DEPARTMENT OF THE ARMY
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GENERALIZED ANALYTICAL COMPUTER PROGRAM FOR TURBOMACHINE-DRIVEN CRYOGENIC SYSTEMS IN HELIUM

by

F. Edward McDonald
Principal Investigator

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U. S. ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT CENTER

Prepared under Contract No. DA-44-009-AMC-787(T) by the University of Colorado, Boulder, Colorado.

FORT BELVOIR, VIRGINIA

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ABSTRACT

In accordance with specified contractural requirements, the present program will analyze any presently foreseeable turbomachine-driven cryogenic aystem in general, employing helium as the working fluid.....and will readout size, weight and performance capebility of each major component.

Likewise, with the planned broad input spectrum, the effect of numerical changes in various selected variables or input parameters may be studied, either individually or in combination with others as deaired.

The cryoganic load, also an elective input variable, may be either wholely within the vapor phase or within the gas phase or partly within both phases as required. These input data are selected from the attached T-S diagram.

It will be noted, however, that the present analytical procedure specifically conaiders the porous-plate type heat exchanger, as recently developed, wherein very high numerical values of "thermodynamic effectiveness" ϵ can be achieved.

Upon activating either one of two input codea, the computer will evaiuate heat exchanger performance based on use of either Al-1100-F or Al-3003-F as the plate material.

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I. INTRODUCTION

The primary purpose of the present work is that of generating an analytical procedure for both study and design of turbomachine-driven cryogenic systems in general, utilizing helium as the working fluid.

In consideration of the comparatively large number of inter-related variables necessary to broad analytical study of these systems, and in order to find either the individual or collective effect of these various parameters on overall system size, weight and performance..... a rather broad input spectrum was indicated.

With this approach, the computer readout not only indicates the comparative effect of changes in the various design parameters, but will guide the designer in optimizing a system design for a particular application.

The present program is so arranged that data specifying the selected cryogenic load is accepted as inputs.....That is to say, upon referring to the T-S diagram Fig. 1, one selects a set of temperatures and pressures that simultaneously defines ths desired cryogenic load. Thus with this election, the selected cryogenic load may be either entirely within the vapor phase, or within the gas phase, or partly within both areas.

It will be noted, howevsr, that only those systems employing a JT-valve (Joule-Thompson expanoion valve) are considered within the present program, therefore selected numerical values for T14 (referring now to both Figs. 1 and 2) must be well below the inversion temperature for helium.....i.e., well below 40°K or 72°R.....Thus for comparatively large cryogenic loads primarily within the vapor phase, one would select T14 at or below 10°R.

In general therefore, referring again to Fig. 1, the computer accepts input data for a specified cryogenic load, and with further input data defining various selected design parameters.....the machine then defines the number and design of the heat exchangers and turbines necessary to reach 540°R within the external low-pressure compressor line.....i.e., outside of the vacuum or cryogenic flask.

It will also be noted that, depending upon the selected numerical values of such inputs as pressure ratio, turbine efficiency ηt, effectiveness ϵ, and etc., some systems may require three turbines while others will require only two.

With the exception of station designations and actual numerical values.....the equations and calculation procedure for HX-3, 5 and 7 is exactly similar to that of HX-1.

Likewise, with the same exceptions, the equations and calculation procedure for HX-4 and 6 is exactly similar to that of HX-2.

II. THE HELIUM T-S DIAGRAM

In order to select numerical load data required for inputs to the main computer program, a portion of the helium T-S diagram is shown in Fig. 1. This map covers the temperature range of 6 to 16°R, and pressures of 10 to 300 psia.....within which area very nearly all presently specified low temperature cryogenic loads will occur.

As an example in the use of Fig. 1, let it be agreed that our desired load is to be wholely within the vapor phase, at say 6.894°R and 10 psia, and that our load exit is to be on the saturated vapor line at this same temperature and pressure. One then selects a JT-valve inlet temperature and pressure comprising T14 and P14. The associated constant H line is then followed down to the point of intersection with the 10 psia line, which establishes T15, P15 and H15 entering the load....Note, here, that H15 equals H14. Then with known values of ΔHfg along the various constant pressure lines (see Table 1), H16 is readily determined. The load ΔH_L is then equal to

$$\Delta H_L = H16 - H15 = BTU/lb \tag{1}$$

and with assigned mass flow W, the cryogenic load in watts is

$$Watts = L_W = 1054.54 \ W \ \Delta H_L \tag{2}$$

The tabulated values of H along both the saturated liquid and saturated vapor lines, and tabulated values of the heatsof vaporization ΔHfg; have been reproduced from ref.(1).

Then as required by the program, all load input data comprising T14, P14, T15, P15, T16, P16 and W, are then known.

III. THE SPECIFIC HEAT EQUATION

In helium, between temperatures of about 40 and 540°R, and for pressures between 10 and 300 psia, the specific heat is essentially a straight line function ranging from approximately 1.38 or so at 40°R, down to about 1.250 BTU/lb°R at 540°R.

In that temperature region between about 6 and 40°R, however, and for pressures between 10 and 300 psia.....the specific heat exhibits very wide excursiona and tends to plot as a rapidly varying carpet, with some disagreement among various authorities.

In view of the considerable complications involved in programming derived specific heat equations for this region, and since the operating conditions of heat exchanger HX-1 will invariably lie within this questionable area, as may part of HX-2.....a special matrix type computer subroutine has been devised, with which cp can be determined. These cp values will closely match the tabulated H values of ref. (1).....i.e. where

$$dH = cp\ dT \tag{3}$$

IV THE PORUS PLATE TYPE HEAT EXCHANGER

The porous plate type heat exchanger considered here is, as its name implies, constructed of a comparatively large number of thin perforated plates (usually of aluminum), with thin plastic separators inserted between each plate.....see ref. (5).

These plastic separators, here assumed as Teflon, are bonded to the aluminum plates and, due to their comparatively low thermal conductivity, also serve to reduce the endwise heat leakage. Should the plastic or other low-thermal-conductivity separators not be employed, the endwise heat loss, by conduction through the aluminum plates, could reach such values that a high thermal effectiveness ϵ could not be attained.

The present state-of-the-art is such that practical numerical values of thermal effectiveness ϵ can approach 99%. At this point, however, any further increase in ϵ is achieved only with considerably increased heat exchanger surface area and physical size.....Thus the economics of a particular application enters at this point.

It therefore is suggested that numerical values of ϵ, whether inputs or computed, be limited to about .985 or .987 throughout comparative studies. Thereafter, should the computer readout values for $\epsilon \geq .987$, one merely alters the associated inputs and continues.

Referring now to Fig. 3.....Here a typical heat exchanger plate is shown in order to define some of the associated nomenclature. It is

to be noted, however, that the present program will accept input data for any of several different mechanical configurations, which variations will be discussed later.

As shown in Fig. 3, flow through the plates occurs through a large number of closely spaced, small diameter holes.

The generalized mathematical relations between hole diameter dh, porosity σ, hole spacing s, and heat transfer surface area Axi per plate per unit of plate face area....have been derived as follows.....

Upon inspection of the magnified or blown up area of Fig. 3-B, one can write

$$\sigma = \frac{\left(\frac{2 \pi dh^2}{4}\right)}{a \cdot b} \tag{4}$$

$$= \frac{\left(\frac{\pi dh^2}{2}\right)}{a \cdot b} \tag{5}$$

Now from the figure,

$$a = 2 (s \sin \alpha) \tag{6}$$

and

$$b = 2 (s \cos \alpha) \tag{7}$$

As employed within the present program, α is assumed and held constant at 30 degrees.

$$\therefore \quad a \cdot b = 4\ s^2 \sin 30° \cdot \cos 30° \tag{8}$$

$$= 1.732060\ s^2 \tag{9}$$

$$\therefore \quad \sigma = \frac{\left(\dfrac{\pi\, dh^2}{2}\right)}{1.73206\ s^2} \tag{10}$$

$$= \frac{.906894\ dh^2}{s^2} \tag{11}$$

Thus

$$s = \sqrt{.906894\ \frac{dh^2}{\sigma}} \tag{12}$$

Here it is suggested, for mechanical and other reasons, that porosity σ be restricted to the range of

$$.40 \leqslant \sigma \leqslant .60 \tag{13}$$

Then the number of holes n_1 per inch ^{2} of plate face area on the hot or driving side, becomes

$$n_1 = \frac{4\ \sigma}{\pi\ dh^2} \tag{14}$$

and the theoretical heat transfer surface area per inch^2 of plate face area is then

$$Ax_1 = (n_1 \pi \, dh \, tp) + 2\,(1-\sigma) \tag{15}$$

Thereafter, the total hole area required for a given flow rate at given velocity, Reynold's Number, etc.....is readily found by solving the continuity equation wherein

$$\frac{W}{A} = \rho V = \frac{V}{\bar{v}} \tag{16}$$

and total hole-flow area in inches^2

$$ah_1 = \frac{144\, W \bar{v}}{V} \tag{17}$$

Therefore total required face area (on one side of the plate and for the hot or driving side only) in inches^2

$$Af_1 = \frac{ah_1}{\sigma} \tag{18}$$

Particular attention is directed to the fact that area requirements are first generated or found on the hot or "driving side" of the heat exchangers.

In addition to the major advantage of very large heat transfer surface area per unit of total volume.....2600 ft^2/ft^3 or more being readily

attainable.....the comparatively thin plates employed (.004 to .010 inches thick) involve such hole length/diameter ratios that, at Reynold's Numbers of 2000 and less.....a laminar boundary layer will not be established.

Under these conditions, i.e., boundary layer thickness approaching zero, it is known that relative Nusselt Numbers (and heat transfer film coefficients) can easily reach numerical values approximately ten times that found in say a long tube after the boundary layer has been established.

For instance, in accordance with ref. (4)

$$N_{Nu} = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{N_{Re} \cdot N_{pr}} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{N_{Re} \cdot N_{pr}} \right]^{.8}} \right)} \right\} \tag{19}$$

at constant wall temperature. Reference (3) also reports similar findings within this area.

In recent exploratory runs with the present program, utilizing a plate thickness tp of .0063 inches and hole diameter dh of .0080 inches.....Nusselt

Numbers approaching 30 have been achieved at reasonable Reynold's Numbers NRe and Prandtl Numbers NPr.

Now since the film coefficient

$$h = \frac{NNu \cdot K}{dh} \tag{20}$$

or

$$h = \frac{12 \quad NNu \cdot k}{dh} \tag{21}$$

(where K is the thermal conductivity of the gas) then the capabilities of the plate type heat exchanger are readily visualized.

Simultaneously referring now to the input section for say HX-1, and to Fig. 3-A.....While the computer evaluates almost all of the physical plate dimensions, working with certain "key" ratios and border dimensions as inputs, some discussion of the related concept is in order.

In general, any desired numerical value can be employed for the various input dimensions and ratios, however, some degree of relative compatibility must also be observed in selection of the various inputs.

For instance, in specifying the C factor and in order to maintain approximately equal heat flow-path-lengths in <u>both</u> the hot-to-cold directions.....it is obvious that a hot strip must always lie between two cold strips. It will also be noted that an <u>external</u> or outside cold flow strip must be one half the height of an <u>internal</u> cold flow strip.....

i.e., $Y2'$ as compared with $Y3'$, and that both $Y2'$ and $Y3'$ will be greater than the associated hot strip height Y_1'.....Thus the selected C factor should always be an odd number, auch as 3, 5, 7, or 9 etc.

$$C = Nh + Nc \tag{22}$$

Then with specified inputs C, Nh, Nc, Fs, Ra, Bx, By and B', the computer determines all other plate dimensions, including the various heat flow-path lengths.

Upon specifying the shape factor Fs, the computer determines all X and Y dimensions required to handle the specified flow at the specified temperature, Pressure and Reynold's Number conditions.

Then with Af_1 known from prior machine calculation, the computer selects

$$X = \text{assume} \tag{23}$$

$$X' = X - (2\ Bx) \tag{24}$$

$$Y' = \frac{X}{Fs} - (2\ By) \tag{25}$$

$$Y_1' = \frac{Y' - \left[(C-1)\ B'\right] - Nh}{2\ (C-1)} \tag{26}$$

$$Af_1 \text{ calculated} = Nh\ (X'\ Y_1') \tag{27}$$

The machine then iterates on X until Af_1 calculated equals Af_1 required.

Thereafter,

$$Y2' = Y_1' \frac{Ra}{2} \tag{28}$$

$$Y3' = Y_1' \cdot Ra \tag{29}$$

$$\ell_1 = \frac{Y_1'}{24} \tag{30}$$

$$\ell_2 = \frac{B'}{12} \tag{31}$$

$$\ell_3 = \frac{Y3'}{12 \cdot Ra} \tag{32}$$

The computer then evaluates required flow areas and various pressure drops.

V. ANALYTICAL TECHNIQUE FOR THE COUNTER-FLOW HEAT EXCHANGER

Within the present program the idea of the ϵ-Ntu or effectiveness-number of heat transfer units approach is employed in counter-flow heat exchanger analysis, wherein thermal effectiveness is defined as

$$\epsilon = \frac{Q}{Qmax} \tag{33}$$

$$= \frac{Ch\ (Th1 - Th2)}{Cmin\ (Th1 - Tc1)} \tag{34}$$

$$= \frac{Cc\ (Tc2 - Tc1)}{Cmin\ (Th1 - Tc1)} \tag{35}$$

where

$$Ch = (W\ \overline{cp})\ \text{hot side} \tag{36}$$

$$Cc = (W\ \overline{cp})\ \text{cold side} \tag{37}$$

and Cmin is the smaller numerical value of the two.

In each case $\overline{cp}$ is either the hot or cold side specific heat integrated over the particular temperature range of interest.

Ntu, usually referred to as the number of heat transfer units, essentially expresses the "thermodynamic size" of the heat exchanger, and is defined by

$$Ntu = \frac{A \cdot Uavg}{Cmin} \tag{38}$$

$$= \frac{1}{Cmin} \int_0^A U \, dA \qquad (39)$$

Referring now to Fig. 4 and deriving further working equations from those of ref. (3).....It will be noted that on the temperature-temperature plane, and with given endpoint temperatures but with no flow present, the thermal equilibrium condition of a counter-flow heat exchanger may be representated by a straight line having the slope dY/dX equal to 1.0. It will also be noted that with no flow present, the endpoinc temperature gradients ∇_1 and ∇_2 are equal to zero.

Upon establishing a finite flow, however, a steady state operating line may ba defined, which operating line will have a slope dY/dX exactly equal to C_{max}/C_{min}.

With this idea in mind, and considering the ϵ-Ntu approach, many useful relations can be derived, which relations permit very rapid and direct analysis as compared with the older log mean -ΔT approach.

Hare attention is directed to the fact, however, that the relative disposition or location of the endpoint temperature gradients ∇_1 and ∇_2 must be carefully observed at all times.

Undar these conditions it can be readily shown that

$$\frac{\nabla_2}{\nabla_1} = e^{-Ntu\left[1-(Cmin/Cmax)\right]} \qquad (40)$$

and that

$$\frac{\nabla_2}{\nabla_1} = \frac{1 - \epsilon}{1 - \epsilon\,(Cmin/Cmax)} \tag{41}$$

Likewise, referring simultaneously to Fig. 5,

$$\Delta X = \frac{\nabla_1 - \nabla_2}{\left(\frac{dY}{dX}\right) - 1} \tag{42}$$

$$= \frac{\Delta Y}{\left(\frac{dY}{dX}\right)} \tag{43}$$

and

$$\Delta Y = \frac{\left[\frac{dY}{dX} \cdot \left(\nabla_1 - \nabla_2\right)\right]}{\left(\frac{dY}{dX}\right) - 1} \tag{44}$$

$$= \frac{dY}{dX} \cdot \Delta X \tag{45}$$

Therefore, in Fig. 4,

$$Y2 = Y_1 + \Delta Y \tag{46}$$

and

$$X2 = X_1 + \Delta X \tag{47}$$

then

$$\nabla_1 = Y2 - X2 \tag{48}$$

and

$$\nabla_2 = Y_1 - X_1 \tag{49}$$

Further, returning to equations (33) through (35),

$$\epsilon = \frac{Q}{Q_{max}} \tag{50}$$

$$= \frac{C_h \cdot \Delta Y}{C_{min}\,(Th_1 - Tc_1)} \tag{51}$$

$$= \frac{C_c \cdot \Delta X}{C_{min}\,(Th_1 - Tc_1)} \tag{52}$$

Upon combining equations (40) and (41), one can arrive at the basic relation

$$\epsilon = \frac{1 - e^{-Ntu\left[1-(C_{min}/C_{max})\right]}}{1 - \left\{\left(\frac{C_{min}}{C_{max}}\right) e^{-Ntu\left[1-(C_{min}/C_{max})\right]}\right\}} \tag{53}$$

where Ch $\neq$ Cc.

In those rare cases where Ch $\equiv$ Cc, that is to say, where

$$\frac{Ch}{Cc} = 1.0 \qquad (54)$$

or vice-versa, then

$$\epsilon = \frac{Ntu}{1 + Ntu} \qquad (55)$$

and

$$Ntu = \frac{\epsilon}{\_ - \epsilon} \qquad (56)$$

The foragoing, and various additional expressions derived therefrom, are employed throughout the main analytical program.

Attention is also directed to the distinction between thermal effectiveness ϵi and ϵ , as employed here.

Since a very considerable amount of iteration on temperature is avoided by analytically finding <u>actual</u> or <u>desired</u> temperature based on a thermal effectiveness ϵi .....and finding <u>required</u> surface area based on calculation with a <u>higher</u> thermal effectiveness ϵ (reflecting the effect of heat loss)..... ϵi and ϵ are not to be considered as "ideal" and "actual" as usually employed.

Here,

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (57)$$

where λ reflects the effect of loss by endwise heat leakage.

This approach is believed to be valid since it can be shown that

$$\frac{Q_{loss}}{Q} \cong \frac{\Delta\epsilon}{\epsilon} = \lambda \tag{58}$$

where

$$\lambda = \frac{\left[(K/l_\epsilon) \quad A_k\right]_{\text{loss path}}}{C_{min}} \tag{59}$$

Therefore, with the inverse problem, equation (57) in effect demands a greater heat transfer surface area, to reach given temperatures, in the presence of heat loss.

VI. HEAT LEAKAGE PATHS NOT CONSIDERED

In addition to the effect of heat loss by endwise conduction, as discussed within Section IV, there remains four possible heat leakage paths which can not be rationally considered within the present generalized analytical program.....since an actual mechanical design or configuration would first be necessary, along with planned grouping or arrangement of the various components.

These additional heat leakage paths are,

1. Radiation between the various system components and the enclosing vacuum-flask walls.
2. Heat conduction through all bracing and support members.
3. Heat conduction through all thermocouple wire leads.
4. And heat conduction through the turbogenerator lead wires (assuming the turbogenerator load to be external of the cryogenic section).

Regarding radiation effects.....Once an actual design and grouping of components has been established, the effect of radiated heat loss from the various components can be readily evaluated with known areas, emissivity and temperature difference by

$$Qr = .173\ \epsilon'\ A_1 \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \qquad (60)$$

where ϵ' is the equivalent emissivity.

Regarding heat loss through bracing and support members.....One possible solution, for minimum heat leakage, is that of employing a strong, low-thermal-conductivity material such as Teflon in these areas, however, an actual established design is required before radiation and conduction loss can be evaluated.

Regarding heat loss through wires.....Here, again, wire length, size and material must necessarily be known before heat loss can be determined. However, it can be noted, at this point, that one or two "cold sinks" may be provided at judicious points along all "bundles" of wire leads, by tapping off coolant from the main string of heat exchangers. The required amount of refrigeration could not be large.

The item 1 and 2 heat loss can and should be charged to affected heat exchangers after a particular system design is established, along with planned physical grouping. This can be accomplished by small modifications within the main program.

In the case of radiation effects, and considering the equations of HX-1 as an example.....Qr can be computed and added to the numerator of such equations as (102), (105) and (108).....which results in a larger λ and, thereby, HX design for greater cooling capacity.

In the case of heat lost by conduction through various bracing and support members, another Q loss can be determined by a group of equations similar to (95) through (101)....This additional Q loss would also be added into the numerator of equations (102), (105) and (108), again using HX-1 as an example.

VII. PROGRAM OPERATIONAL PROCEDURE

Referring now to Fig. 2.....The computer is instructed to "stack" or employ any number of turbogenerators up to a maximum of three, and any number of heat exchangers up to a maximum of seven..... as required to reach the selected temperature of 540°R in the external low pressure compressor line, shown here as station 23.

In general, however, two turbogenerators and five heat exchangers will usually be sufficient to reach any desired cryogenic load temperature, in helium, from 540°R. On the other hand, since it may be desirable to study very low pressure ratio-low efficiency systems for some particular application, the analytical capability to handle three turbines and seven heat exchangers has been incorporated within the program.

In good rational system design, this ambient condition should be reached either at station 21 for two-turbine designs, or at station 23 for three-turbine systems.....This means that a final heat exchanger should always be employed above the final turbine, since considerable "cooling capability" is always present within the turbine exit flow stream.

Therefore, in those cases where the desired final exit temperature (540°R as employed here) is either exceeded, or not reached, with a given set of inputs.....one merely alters various inputs until the desired exit conditions are achieved. It may be noted that in those cases where it

is desirable to retain certain input values, a change in overall system pressure ratio will usually serve the purpose.

In actual practice it has been found that little is to be gained in driving or forcing actual heat exchanger effectiveness ϵ to values greater than say .985 to .987 since, at this point, heat exchanger size and weight tends to increase rapidly.

In "driving" or loading heat exchangers up to their economic limit, however, it should be observed that in those cases where the "corner" temperatures are controlled by turbine thermodynamics, i.e. turbine inlet and exit temperatures, nothing other than added weight will be gained by adding plates in an effort to increase ϵ.....That is to say, where the turbine establishes such corner temperatures that reflect a heat exchanger effectiveness of say only .820, nothing is to be gained by designing that particular heat exchanger for an ϵ of say .980..... This situstion can be encountered st HX-2, HX-4 and HX-6.

As a fine point in further refinement of hest exchanger design, attention is directed to the "fin effectiveness" η_f, which values are readout as a result of equations (126)(for HX-1,3,5,7) and (125) (for HX-2,4,6).....Experience to date has shown thst best optimizstion will usually occur when numerical values of η_f are restricted to

$$.40 \leqslant \eta_f \leqslant .60 \tag{61}$$

In those casea where η_f tends to fall beyond these limits, one can usually force η_f into this desired range by altering the numerical

value of the "shape factor" Fs, which factor is listed as an input for all HX components. The net effect of the foregoing is that of optimizing (to a limited extent) the various heat flow-path lengths which, in effect, tends to utilize plate material more economically.

It will also be observed that turbine efficiency per se will have little effect on overall system performance at <u>very low temperature levels</u>. However, at higher temperature levels, i.e. for turbine 2 (and turbine 3 where employed), higher turbine efficiency will permit greater work extraction and will result in the more effective overall system. This effect can be demonstrated as follows.....

Since

$$\eta t = \frac{1 - \dfrac{T2}{T1}}{1 - (P2/P1)^{(\bar{\gamma}-1)/\bar{\gamma}}} \tag{62}$$

$$1 - \frac{T2}{T1} = \eta t \left[1 - (P2/P1)^{(\bar{\gamma}-1)/\bar{\gamma}}\right] \tag{63}$$

$$\frac{T2}{T1} = 1 - \eta t \left[1 - (P2/P1)^{(\bar{\gamma}-1)/\bar{\gamma}}\right] \tag{64}$$

Now if T1 is say only 4 or 5 degrees, T2 can not possibly be much lower, numerically.....regardless of turbine efficiency and pressure ratio.

On the other hand, however, at higher temperature levels such as 100, 200, 300 degrees, it is obvious that the highest possible turbine efficiency and/or pressure ratio will effectively extract a much larger amount of heat (work).....therefore use of the highest attainable turbine efficiency is recommended, regardless of pressure ratio.

Within all analytical work, referring again to Fig. 2, particular attention is directed to the fact that T16 through T23 can never be equal to or greater (respectively) than T14 through T7.....as a violation of the Second Law would be involved.

In general, within the temperature-iterative procedures, the program is so arranged that the machine will not select a numerical value in violation of the Second Law.

VIII. INPUT PREPARATION

Referring now to Appendix I.....Section I of the input data is concerned with the selected cryogenic load, of which some numerical vslues are employed in calculation while others are entered and readout for identification and record purposes only.

For the JT-valve inlet, one selects desired numerical values for T14, P14, H14 and S14, either from the attached T-S Diagram Fig. 1, or from the Tables of ref. (1).

For the JT-valve exit conditions (load inlet), the associated constant H line (Fig. 1) is followed down to the desired load inlet pressure and T15, P15, H15 and S15 values are recorded. (Note here that H15 will equal H14.)

For the losd exit, one then selects desired values for T16, P16, H16 and S16. Then with these values the load ΔHL is determined by

$$\Delta HL = H16 - H15 = BTU/lb \tag{65}$$

and actual watts

$$Lw = 1054.54 \quad W_1 \cdot \Delta HL \tag{66}$$

. . . . .

Input data for Section II.....Section II is concerned with the inputs for the first heat exchanger HX-1. In generel, a major portion

of the input data is related to plate and hole sizing, as discussed within Section IV of the text, and is self explanatory. It should be noted, however, particularly in relation to Reynold's Number N_{Re_1}, that the computer is instructed to handle laminar flow only, therefore numerical values initially selected for N_{Re_1} should be restricted to 2,000 or less. In those cases where limiting environmental conditions are encountered, the computer will readout a message requesting a smaller N_{Re_1}.

Values for the plate porosity σ, as discussed elsewhere within the text, should be limited to the range of .40 to .60.

While the number of heat transfer units Ntui can theoretically reach any numerical value, the computer is also instructed to readout a message calling for less Ntui when limiting environmental conditions have been encountered. While any value that the machine will accept can be employed, numerical values in the order of 10 or so are suggested for initial runs. Thereafter, in order to drive the heat exchanger to its economical limit, or in optimizing a heat exchanger, one can increase these values until this or some other limit is encountered.

The remaining dimensional and/or shape factors or ratios C, Nc, Nh, Fs and Ra are discussed in the text, within Section IV. For instance, C is the sum of all the flow strips, i.e.,

$$C = Nc + Nh \tag{67}$$

Nc and Nh are the selected number of cold and hot flow strips or face areas (see Fig. 3), and will always be in the following relation

$$Nh = Nc - 1 \tag{68}$$

and

$$Nc = Nh + 1 \tag{69}$$

The factor Ra reflects the ratio by which $Y3'$ is greater than $Y1'$. For inatance Fig. 3-A, as drawn, reflects an Ra factor of 4.0.

The ahape factor Fa is numerically selected at some value greater than 1.0, in thoae casea where it is desirable to have a rectangular rather than square crosa-aection heat exchanger.....without specifying either X or Y.....In those caaes where a square croas-section is desired, the numerical value of 1.0 ia inaerted.....With a specified value for Fs, the computer will determine the required X-Y values in consideration of the local environment of temperature, preasure and flow.

The flow factor Rf ia not directly employed for calculation purposes within the program, but ia entered as a record of the mass flow ratio within the heat exchanger. Therefore

$$Rf = \frac{W \text{ cold side}}{W \text{ hot aide}} \tag{70}$$

It will be noted that for HX-1, 3, 5 and 7, Rf will always equal 1.0 since the cold aide flow must equal that of the hot side. Within HX-2, 4 and 6, however, the cold side flow will always be greater than the hot side by an amount equal to the aasociated turbine flow.....Hence Rf reflects the choice of turbine flow relative to the hot side flow. Thus

$$Rf = \frac{Wt + Wh}{Wh} \tag{71}$$

$$= \frac{Wc}{Wh} \tag{72}$$

The numerical value for (1P-31) "CODE," will in all cases be aelected as either 1 or 2. Upon inaerting the value of 1, the computer will assume the plate material Al-1100-F, and will determine HX-1 aize based on this material. Upon inserting the CODE value 2, the computer will evaluate the heat exchanger (HX-1) based on use of Al-3003-F material.

. . . . .

Input data for Section III.....Section III ia concerned with the input data for heat exchanger HX-2 and turbina 1.

While the input valuea for HX-2 and turbine 1 may be numerically different from those of HX-1, they are aimilar in character, with certain deletions and additional data.

Since the preaence of turbine 1 now controls two of the HX-2 end-point or "corner" temperatures, Ntui becomea a calculated result and, therefore, can not be used aa an input.

Also, since it ia desirable to aee the effect of various turbine efficiency levels on overall ayatem performance, turbine efficiency η_t is added as an input.....In running the program it is suggested that numerical values be restricted to the range of .30 to .90 or ao.

Since a turbine "bridges" HX-2, it will be noted (see Fig. 2) that the cold side flow will be greater than that of the hot side, therefore three flows are now specified.....W_1 for the hot side, W_{t1} for turbine, and W2 for the cold side.

No restriction is placed on numerical values for these flows other than the following.....Upon inspection of Fig. 2, it will be noted that W_1 must obviously equal the flow through HX-1.....W_{t1} can be any desired value, limited primarily by acceptable Reynold's Number, pressure drop, size of the equipment, and similar limits imposed by all upstream heat exchangers.....W2 must obviously equal W_1 plus W_{t1}.

In regards to the heat exchanger material CODE, either 1 or 2 is inserted here in accordance with the desired material.

. . . . .

Input data for all other sections.....Here, it will be seen that all input data for HX-3, HX-5, and HX-7 is exactly similar, in character, to that of HX-1.....and all input data for HX-4 and HX-6 (including the respective turbines 2 and 3) is exactly similar, in character, to that of HX-2 and turbine 1.

IX. CONCLUSIONS AND RECOMMENDATIONS

From various exploratory runs in checking out the complete program, it is felt that the porous-plate type heat exchanger is probably one of the few configurations capable of reaching very low temperatures, with reasonable component size and weight.

It has been noted, however that while the stack of plates with plastic separators are bonded into a solid asaembly as it were, these heat exchangers are mechanically very weak in the endwise direction and would tend to separate a appreciable internal pressure is applied..... Therefore, with the present state-of-the-art, these unita must be tightly clamped or held in bolted fixtures such that endwiae "blowout" pressure can be resisted.

Their radial resistance to internal pressure is apparently much higher as seen by inapection of Fig. 3, and they have been known to withstand differential preaaurea of aome 2 or 3 atmoapherea. It ia conceivable, however, that the plaatic aeparatora would or could blowout at preasure differentials exceeding say 4 or 5 atmoapherea.

Since it may be desirable to deaign future cryogenic systems with pressure ratios in the order of 8 or 10/1 or more, it is recommended that tests be made with a heat exchanger firat wrapped with a plaatic layer, e.g. Teflon, then tightly wrapped with a single layer of amall diameter, high strength wire.....in addition to endwise bolting or clamping.

X. NOMENCLATURE

Symbol:	Entity:	Units:
A	Area in general	ins^2 or ft^2
Af1	Plate face area, hot side	ins^2
Akl	Face area of heat loss path	ft^2
Ax1	Heat transfer surface area per in^2 face area, hot side	ins^2
Axp	Total heat transfer surface area per plate, hot side	ins^2
Ax tot.hs	Total heat transfer surface area, hot side	ft^2
Av	Total hot side heat transfer surface area per unit total volume	ft^2/ft^3
ah1	Total hole flow area, hot side	ins^2
ah2	Total hole flow area, cold side	ins^2
Bx	External border dimension	ins
By	External border dimension	ins
B'	Internal border dimension	ins
C	Configuration factor	= Nh + Nc
Cc2	Heat flow potential, cold side	= W cpcm
Ch1	Heat flow potential, hot side	= W cphm
cp	Specific heat at constant pressure	BTU/lb °R
$\overline{cp}$	Mean specific heat	BTU/lb °R
cpcm	Mean specific heat, cold side	BTU/lb °R
cphm	Mean specific heat, hot side	BTU/lb °R
dh	Hole diameter	ins
e	Base of natural logarithm	2.7182818 etc.

Symbol:	Entity:	Units:
Fs	Shape factor	X/Y
H	Total heat	BTU/lb
Hf	Total heat in fluid or liquid atate	BTU/lb
Hg	Total heat in gas state	BTU/lb
ΔH	Total heat change	BTU/lb
ΔHfg	Latent heat of vaporization	BTU/lb
ΔHL	Total heat load	BTU/lb
ΔHt	Total turbine work	BTU/lb
h	Film coefficient	BTU-ft/hr-ft^2°R
K	Thermal conductivity	BTU-ft/hr-ft^2°R
$\overline{K\ell}$	Thermal conductivity, loss path	BTU-ft/hr-ft^2°R
Km	Mean thermal conductivity	BTU-ft/hr-ft^2°R
Kp	Plate thermal conductivity	BTU-ft/hr-ft^2°R
L	A length	ins or ft
LG	Logic gate in computer program	-
Lw	Total cryogenic load	Watts
ℓ_1	A heat flow path length	ft
$\ell 2$	A heat flow path length	ft
$\ell 3$	A heat flow path length	ft
ℓc	A heat flow path length, loss	ft
Nc	Number of cold flow strips, see Fig. 3	-
Nh	Number of hot flow strips, see Fig. 3	-

Symbol:	Entity:	Units:
N_{Nu}	Nusselt Number	$4h \cdot r_h/K$
N_{Pr}	Prandtl Number	$c_p \cdot \mu/K$
N_{Re}	Reynold's Number	$d_h V/\bar{\nu}\ \mu$
Ntu	Number of heat transfer units, see text	AU/Cmin
nl	Number of holes per in^2 face area, hot side	–
np	Number of plates in heat exchanger	–
ns	Number of spacers in heat exchanger	np + 1
P	Pressure	psia
ΔP	Pressure difference, actual	psia
$\Delta P'$	Pressure difference, loss	psia
Pcm	Mean Pressure, cold side	psia
Phm	Mean Pressure, hot side	psia
Q	A quantity of heat	BTU
Ql	A quantity of heat, loss	BTU
Qmax	Maximum available quantity of heat	BTU
Ra	Face area ratio per plate	cold side/hot side
Rf	Flow ratio	cold/hot
S	Entrophy	BTU/lb °R
s	Hole spacing, center to center	ins
T	Temperature	°R
Tcm	Mean temperature, cold side	°R
Thm	Mean temperature, hot side	°R
Tlc	Mean temperature, cold end	°R

Symbol:	Entity:	Units:
$T_{\ell 2}$	Mean temperature, hot end	°R
T_x	Average temperature, hot to cold side	°R
t_p	Plate thickness	ins
t_s	Spacer thickness	ins
U	Overall heat transfer coefficient	BTU-ft/hr-ft^2°R
V	Velocity	ft/sec
$\bar{v}$	Specific volume	ft^3/lb
W	Flow in general	lbs/sec
W_1	Flow at various points in system, see Fig. 2	lbs/sec
W_2	Flow st various points in system, see Fig. 2	lbs/sec
W_3	Flow st various points in system, aee Fig. 2	lbs/sec
W_4	Flow at vsrious points in system, see Fig. 2	lbs/sec
W_{t1}	Turbine 1 flow	lbs/sec
W_{t2}	Turbine 2 flow	lbs/sec
W_{t3}	Turbine 3 flow	lbs/sec
X	External dimension, see Fig. 3	ins
X'	Internal dimension, see Fig. 3	ins
ΔX	Temperature difference, cold side	°R
Y	External dimension, see Fig. 3	ins
Y'	Internal dimension, see Fig. 3	ins
Y_1'	Internal dimension, see Fig. 3	ins
Y_2'	Internal dimension, see Fig. 3	ins
Y_3'	Internal dimension, see Fig. 3	ina
ΔY	Temperature difference, hot side	°R

Symbol:	Entity:	Units:
∇_1	Temperature gradient, hot end, see Figs. 4 & 5	°R
∇_2	Temperature gradient, cold end, see Figs. 4 & 5	°R
Z	Maximum temperature difference	°R
∞	Infinity	-
	Greek:	
α	An angle	degrees
γ	Specific heat ratio	cp/cv
$\bar{\gamma}$	Mean specific heat ratio	cp/cv
ϵ	Actual heat exchanger effectiveness, with loss	Q/Qmax
ϵ_i	Ideal exchanger effectiveness, no loss	Q/Qmax
η_f	Fin effectiveness, see equation (124) in HX-1	-
η_t	Turbine efficiency	% x 10^{-2}
λ	A heat loss function	-
μ	Viscosity	lbs/ft sec
π	Circumference to diameter ratio of the circle	3.14159
σ	Porosity	hole area/in^2 face area
	Subscripts:	
1	Location identification, see various Figures	-
2	Location identification, see various Figures	-
3 etc	Location identification, see various Figures	-
avg	Average	-
c	Cold	-
h	Hot	-

XI. [illegible]

1. Ma[illegible] D. B.
   The thermodynamic properties of helium from
   [illegible] to 540°R between 10 and 1500 psia.
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2. [illegible] W., and Duke, W. M.
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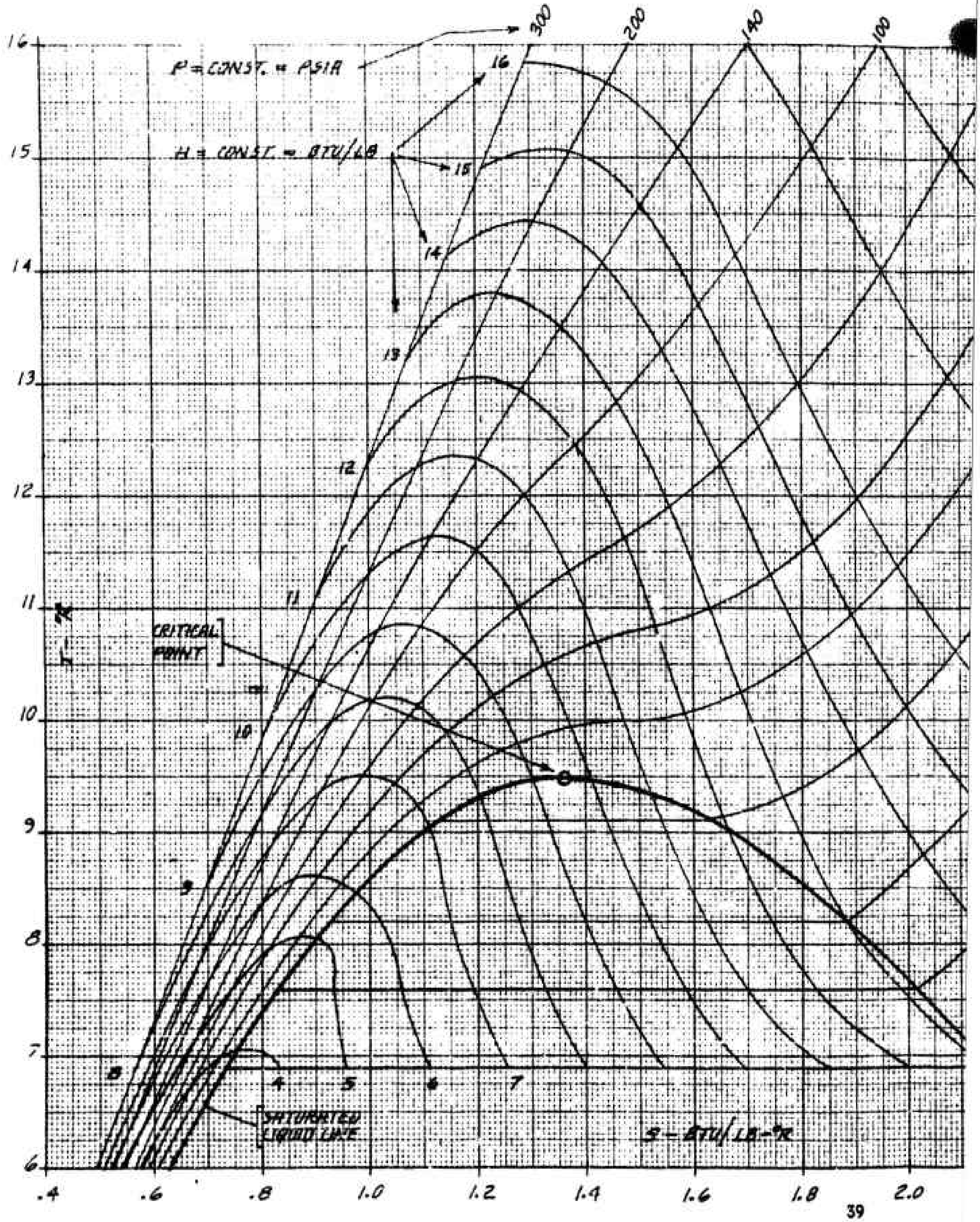
3. Kays, W. M., and London, A. L.
   Compact heat exchangers.
   McGraw-Hill, 2nd ed., 1964.

4. Knudsen, J. G., and Katz, D. L.
   Fluid dynamics and heat transfer.
   McGraw-Hill, 1958.

5. Fleming, R. B.....in
   Advances in cryogenic engineering.
   Plenum Press, Vol. 14, 1969.

XII. FIGURES AND TABLES


P = CONST. = PSIA
H = CONST. = BTU/LB
300
200
140
100
16
15
14
13
12
11
10
9
8
7
6
5
4
CRITICAL POINT
SATURATED LIQUID LINE
T - °R
S - BTU/LB-°R
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0

A

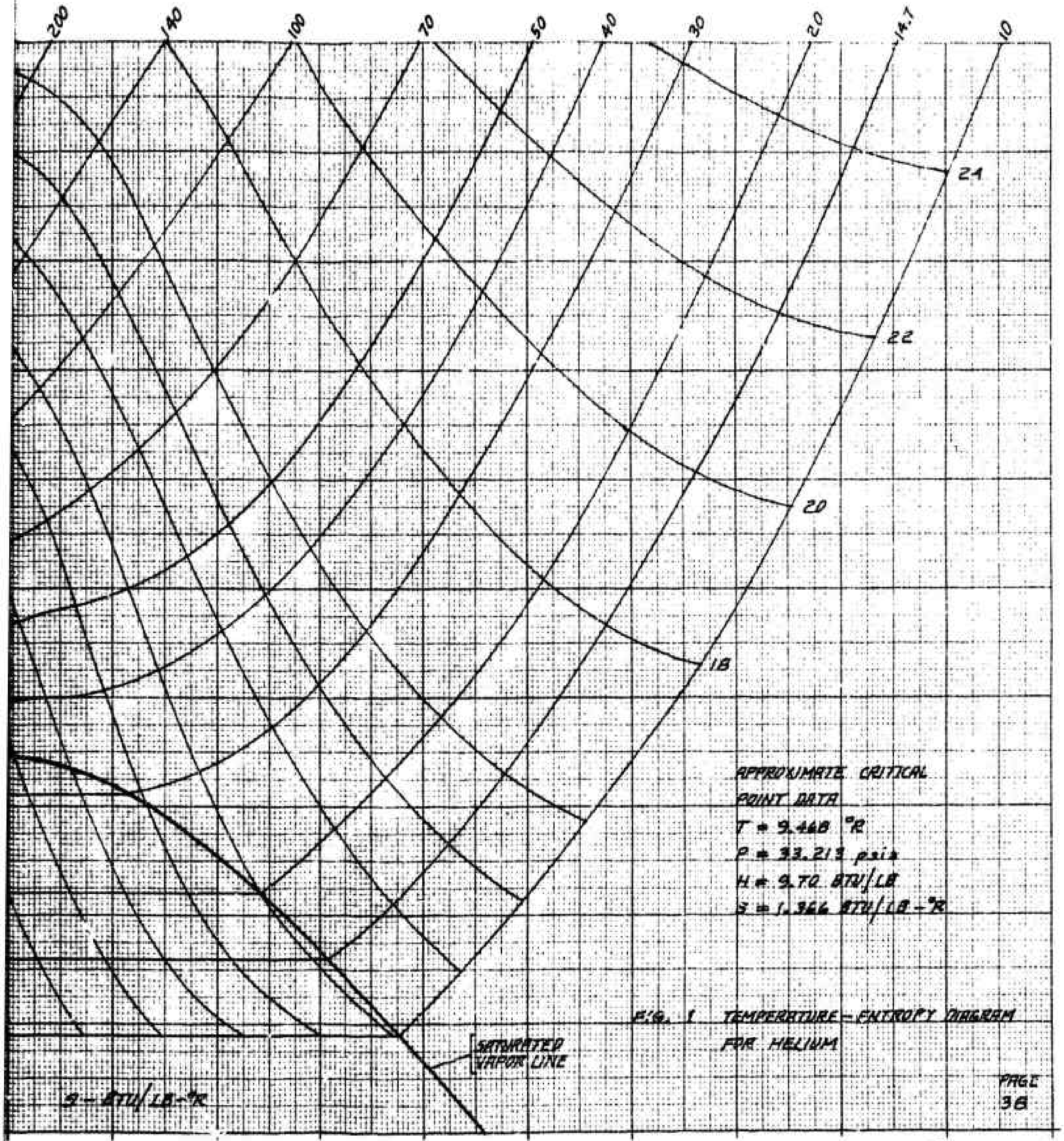


FIG. 1 TEMPERATURE-ENTROPY DIAGRAM FOR HELIUM

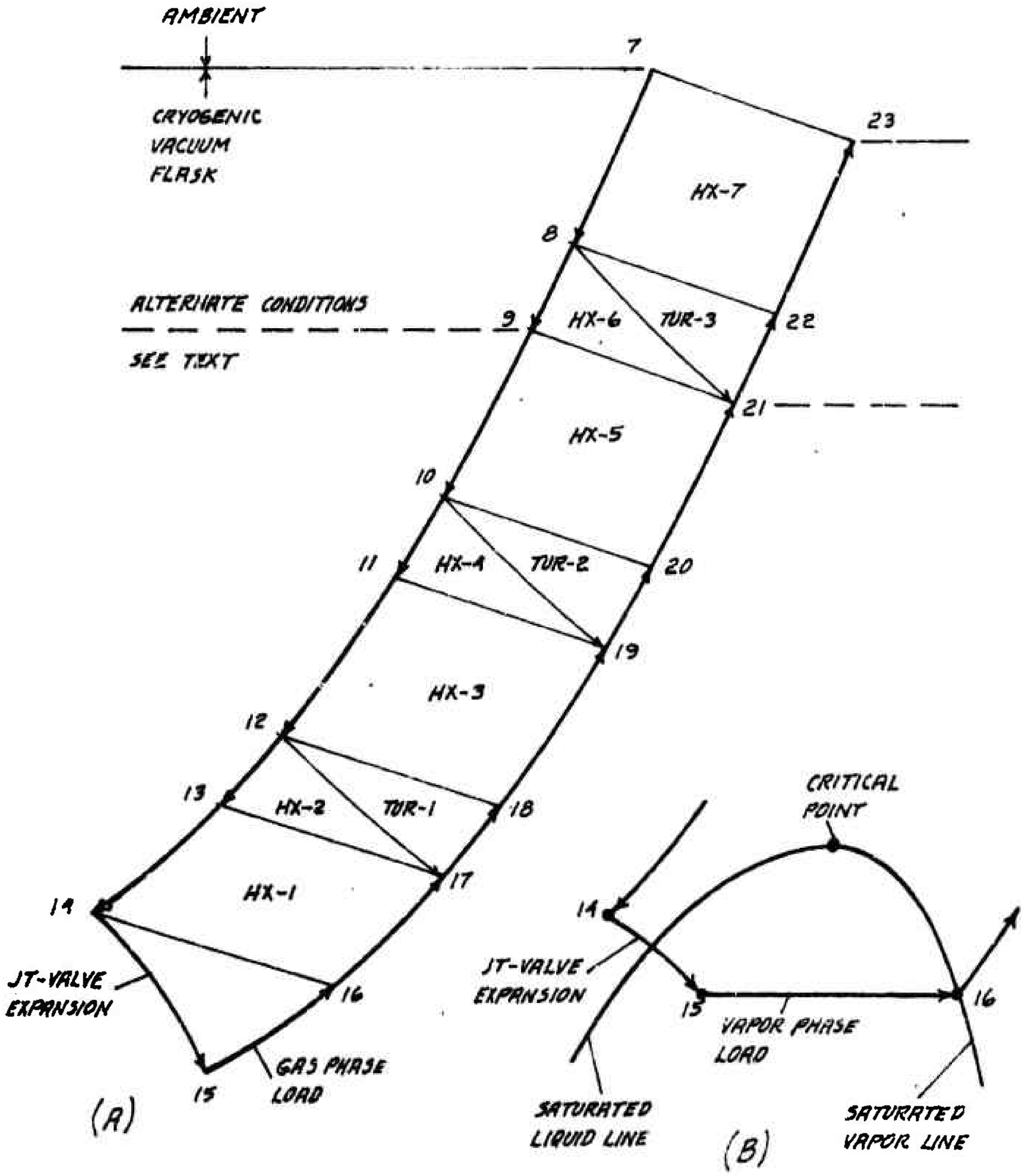


FIG. 2 CRYOGENIC SYSTEM ON THE T-S PLANE
EXTERNAL COMPRESSORS NOT SHOWN

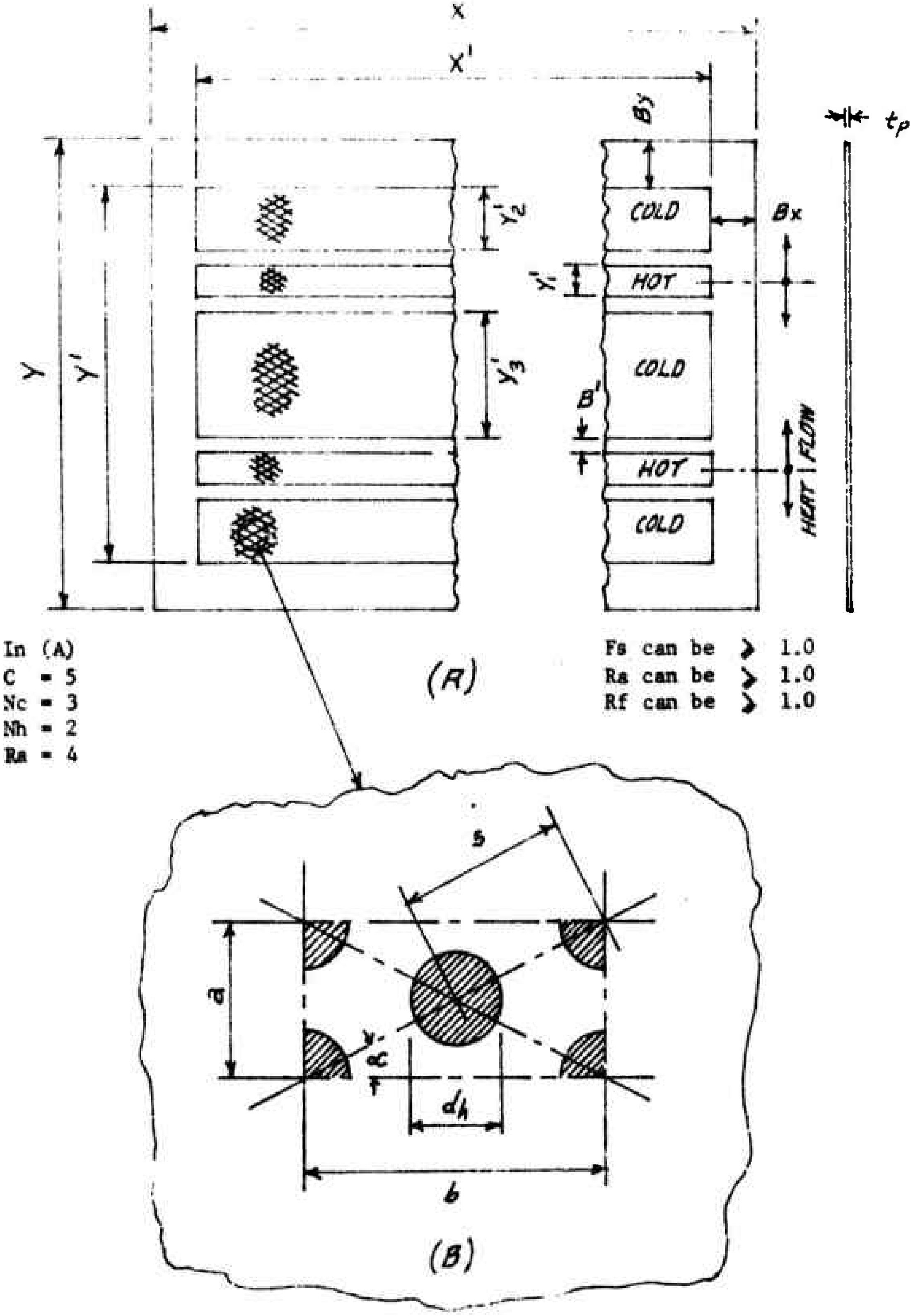
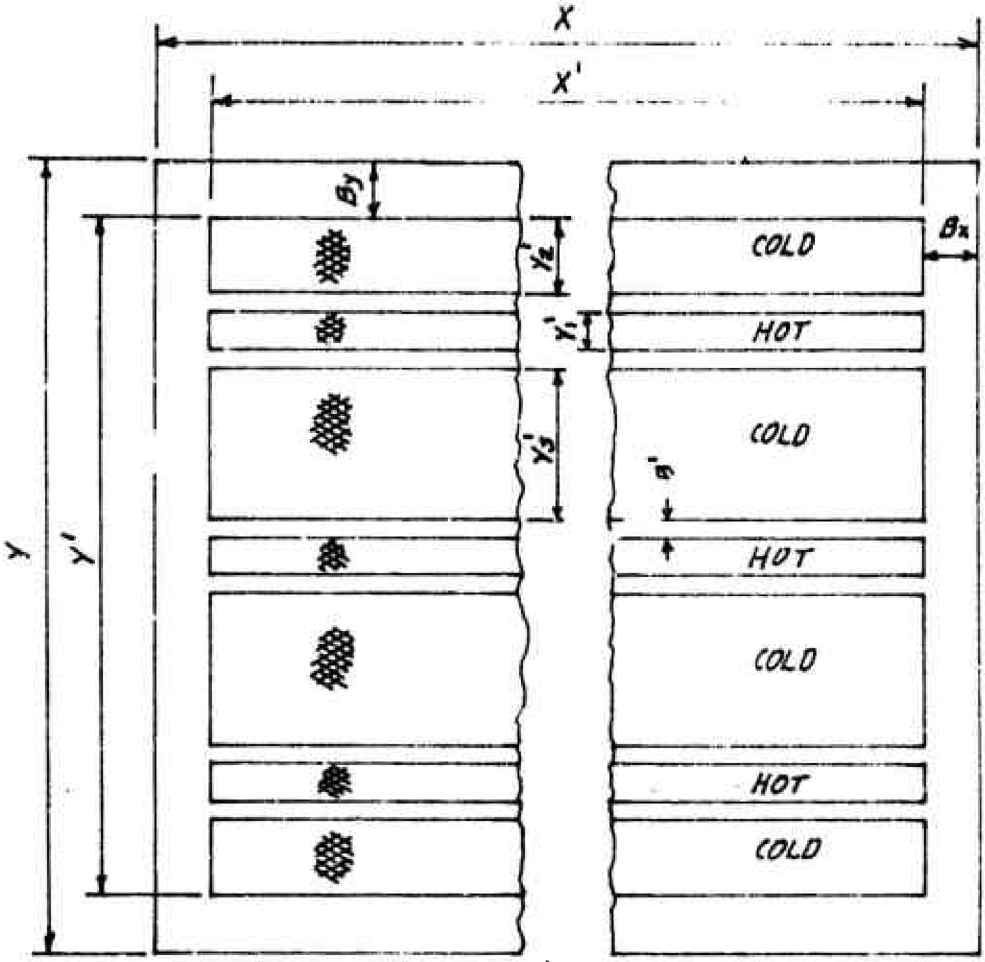


FIG. 3 GENERALIZED PLATE CONFIGURATION AND DIMENSIONS.
GAS FLOW THROUGH HOLES.
HEAT FLOW THROUGH METAL IN Y DIRECTION.



In (C)
C = 7
Nc= 4
Nh= 3
Ra= 4

(C)

Fs can be $\geq$ 1.0
Ra can be $\geq$ 1.0
Rf can be $\geq$ 1.0

FIG. 3 CONTINUED

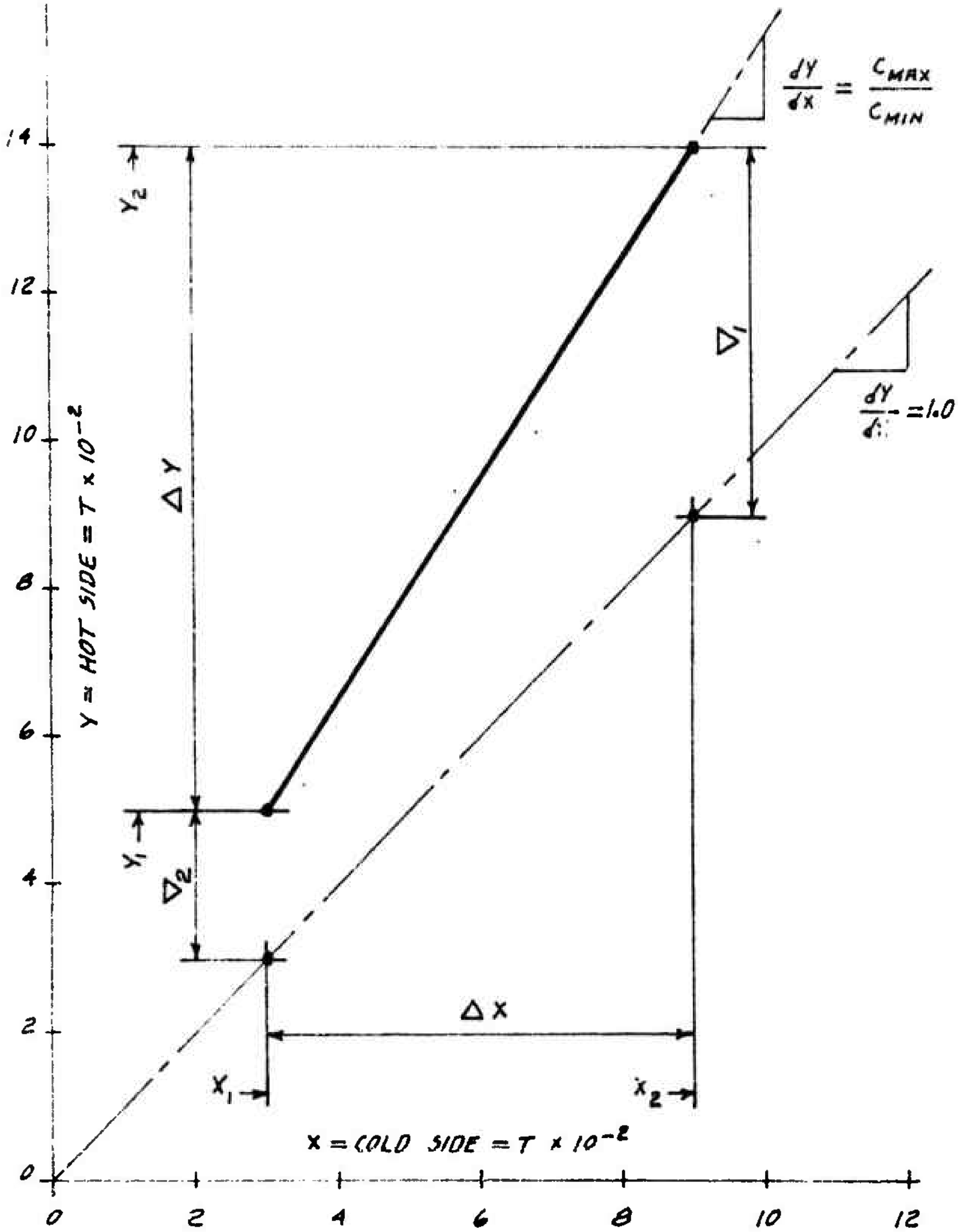


FIG. 4 COUNTER-FLOW HEAT EXCHANGER ON THE TEMPERATURE - TEMPERATURE PLANE

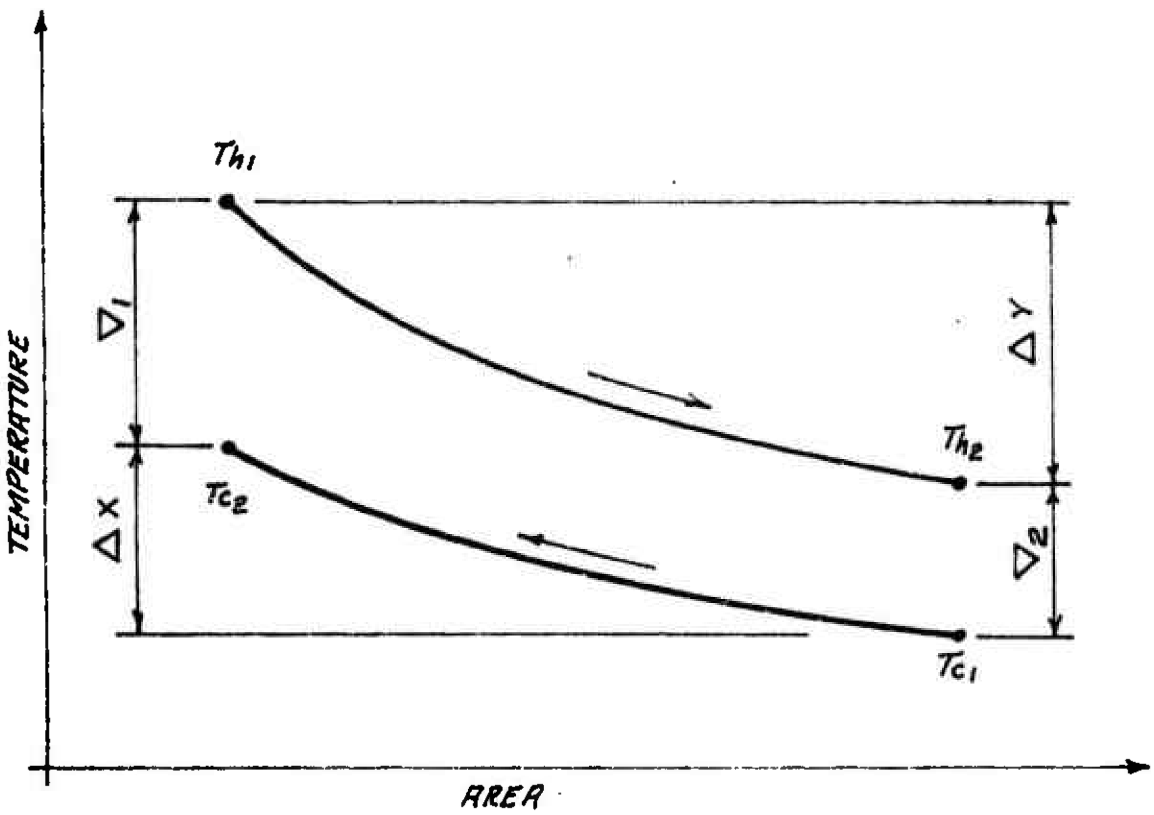


FIG. 5 COUNTER-FLOW HEAT EXCHANGER ON THE TEMPERATURE-AREA PLANE

TABLE I HEATS OF VAPORIZATION:

T°R:	P psia:	Hl:	Sl:	Hg:	Sg:	ΔHfg:
6.0	5.58	2.70	.630	12.81	2.315	10.11
6.2	6.44	2.81	.653	12.91	2.271	10.10
6.4	7.35	3.02	.675	12.99	2.231	9.97
6.6	8.35	3.20	.700	13.06	2.195	9.86
6.8	9.44	3.38	.725	13.13	2.160	9.75
7.0	10.64	3.58	.750	13.17	2.125	9.59
7.2	11.93	3.79	.778	13.21	2.095	9.42
7.4	13.31	4.01	.805	13.23	2.050	9.22
7.6	14.80	4.28	.831	13.23	2.010	8.95
7.8	16.43	4.56	.861	13.21	1.970	8.65
8.0	18.13	4.84	.890	13.15	1.928	8.31
8.2	19.90	5.16	.902	13.05	1.886	7.89
8.4	21.85	5.50	.957	12.90	1.841	7.40
8.6	23.91	5.88	.996	12.72	1.794	6.84
8.8	26.28	6.34	1.042	12.45	1.738	6.11
9.0	28.53	6.88	1.098	12.05	1.672	5.17

NOTES.....All temperature = °R

All pressure = psia

All H = BTU/lb

All S = BTU/lb - °R

From ref. (1)

Use with Fig. 1 in preparing load inputs.

APPENDIX I

INPUT DATA

Note.....Readout all inputs for record purposes.

I. LOAD DATA:

At JT-valve inlet:

Input No:	Entity:		Numerical Value:	Units:
(IP-1)	T14	Temperature		°R
(IP-2)	P14	Pressure		psia
(IP-3)	H14	Enthalpy		BTU/lb
(IP-4)	S14	Entropy		BTU/lb°R

At JT-valve exit:

(IP-5)	T15	Temperature		°R
(IP-6)	P15	Pressure		psia
(IP-7)	H15	Enthalpy		BTU/lb
(IP-8)	S15	Entropy		BTU/lb°R

At load exit:

(IP-9)	T16	Temperature		°R
(IP-10)	P16	Pressure		psia
(IP-11)	H16	Enthalpy		BTU/lb
(IP-12)	S16	Entropy		BTU/lb°R
(IP-13)	ΔHL	Load		BTU/lb
(IP-14)	Lw	Load		Watts

II. HX-1 DATA:

Input No:	Entity:		Numerical Value:	Units:
(IP-15)	dh	Hole diameter		inches
(IP-16)	tp	Plate thickness		inches
(IP-17)	ts	Spacer thickness		inches
(IP-18)	σ	Porosity		hole area/face area
(IP-19)	N_{Re1}	Reynold's Number, hot side		$d_hV/\overline{\nu}\mu$
(IP-20)	N_{tu1}	Number of heat transfer units, hot side		
(IP-21)	C	Configuration factor		
(IP-22)	Nh	Number of hot flow strips		
(IP-23)	Nc	Number of cold flow strips		see text
(IP-24)	Fs	Shape factor		
(IP-25)	Ra	Face area ratio		
(IP-26)	Rf	Flow ratio		
(IP-27)	Bx	External border dimension		inches
(IP-28)	By	External border dimension		inches
(IP-29)	B'	Internal border dimension		inches
(IP-30)	W_1	Flow		lbs/sec
(IP-31)	CODE	Plate material		see note

III. HX-2 AND TURBINE 1 DATA:

(IP-32)	dh	Hole diameter		inches
(IP-33)	tp	Plate thickness		inches

Input No:	Entity:		Numerical Value:	Units:
(IP-34)	ts	Spacer thickness		inches
(IP-35)	σ	Porosity		hole area/face area
(IP-36)	NRe1	Reynold's Number, hot side		$dhV/\bar{\nu}\mu$
(IP-37)	C	Configuration factor		
(IP-38)	Nh	Number of hot flow strips		
(IP-39)	Nc	Number of cold flow strips		see text
(IP-40)	Fa	Shape factor		
(IP-41)	Ra	Face area ratio		
(IP-42)	Rf	Flow ratio		
(IP-43)	Bx	External border dimension		inches
(IP-44)	By	External border dimension		inches
(IP-45)	B'	Internal border dimension		inches
(IP-46)	W1	Hot side flow		lbs/sec
(IP-47)	Wt1	Turbine flow		lbs/sec
(IP-48)	W2	Cold side flow		lbs/sec
(IP-49)	ηt	Turbine efficiency		$\% \times 10^{-2}$
(IP-50)	CODE	Plate material		see note

IV. HX-3 DATA:

(IP-51)	dh	Hole diameter		inches
(IP-52)	tp	Plate thickness		inches
(IP-53)	ts	Spacer thickness		inches

Input No:	Entity:		Numerical Value:	Units:
(IP-54)	σ	Porosity		hole area/face area
(IP-55)	N_{Re_1}	Reynold's Number, hot side		$d_h V / \bar{\nu} \mu$
(IP-56)	N_{tu_1}	Number of heat transfer units, hot side		↑
(IP-57)	C	Configuration factor		
(IP-58)	Nh	Number of hot flow strips		
(IP-59)	Nc	Number of cold flow strips		
(IP-60)	Fs	Shape factor		see text
(IP-61)	Ra	Face area ratio		
(IP-62)	Rf	Flow ratio		↓
(IP-63)	Bx	External border dimensions		inches
(IP-64)	By	External border dimension		inches
(IP-65)	B'	Internal border dimension		inches
(IP-66)	W2	Flow		lbs/sec
(IP-67)	CODE	Plate material		see note

V. HX-4 AND TURBINE 2 DATA:

(IP-68)	dh	Hole diameter		inches
(IP-69)	tp	Plate thickness		inches
(IP-70)	ts	Spacer thickness		inches
(IP-71)	σ	Porosity		hole area/face area
(IP-72)	N_{Re_1}	Reynold's Number, hot side		$d_h V / \bar{\nu} \mu$

Input No:	Entity:		Numerical Value:	Units:
(IP-73)	C	Configuration factor		↑
(IP-74)	Nh	Number of hot flow strips		
(IP-75)	Nc	Number of cold flow strips		see text
(IP-76)	Fs	Shape factor		
(IP-77)	Ra	Face area ratio		
(IP-78)	Rf	Flow ratio		↓
(IP-79)	Bx	External border dimension		inches
(IP-80)	By	External border dimension		inches
(IP-81)	B'	Internal border dimension		inches
(IP-82)	W2	Hot side flow		lbs/sec
(IP-83)	Wt2	Turbine flow		lbs/sec
(IP-84)	W3	Cold side flow		lbs/sec
(IP-85)	ηt	Turbine efficiency		% x 10^{-2}
(IP-86)	*CODE	Plate material		see note

VI. HX-5 DATA:

(IP-87)	dh	Hole diameter		inches
(IP-88)	tp	Plate thickness		inches
(IP-89)	ts	Spacer thickness		inches
(IP-90)	σ	Porosity		hole area/face area
(IP-91)	NRe1	Reynold's Number, hot side		$dhV/\overline{\nu}\mu$

Input No:	Entity:		Numerical Value:	Units:
(IP-92)	Ntuh	Number of heat transfer units, hot side		↑
(IP-93)	C	Configuration factor		
(IP-94)	Nh	Number of hot flow strips		
(IP-95)	Nc	Number of cold flow strips		see text
(IP-96)	Fs	Shape factor		
(IP-97)	Ra	Face area ratio		
(IP-98)	Rf	Flow ratio		↓
(IP-99)	Bx	External border dimension		inches
(IP-100)	By	External border dimension		inches
(IP-101)	B'	Internal border dimension		inches
(IP-102)	W3	Flow		lbs/sec
(IP-103)	CODE	Plate material		see note

VII. HX-6 AND TURBINE 3 DATA:

(IP-104)	dh	Hole diameter		inches
(IP-105)	tp	Plate thickness		inches
(IP-106)	ts	Spacer thickness		inches
(IP-107)	σ	Porosity		hole area/face area
(IP-108)	NReh	Reynold's Number, hot side		$dhV/\overline{\nu}\mu$
(IP-109)	C	Configuration factor		see text
(IP-110)	Nh	Number of hot flow strips		see text

Input No:	Entity:		Numerical Value:	Units:
(IP-111)	Nc	Number of cold flow strips		↑
(IP-112)	Fs	Shape factor		
(IP-113)	Ra	Face area ratio		see text
(IP-114)	Rf	Flow ratio		↓
(IP-115)	Bx	External border dimension		inches
(IP-116)	By	External border dimension		inches
(IP-117)	B'	Internal border dimension		inches
(IP-118)	W3	Hot side flow		lbs/sec
(IP-119)	Wt3	Turbine flow		lbs/sec
(IP-120)	W4	Cold side flow		lbs/sec
(IP-121)	ηt	Turbine efficiency		% x 10^{-2}
(IP-122)	CODE	Plate material		see note

VIII. HX-7 DATA:

(IP-123)	dh	Hole diameter		inches
(IP-124)	tp	Plate thickness		inches
(IP-125)	ts	Spacer thickness		inches
(IP-126)	σ	Porosity		hole area/face area
(IP-127)	NRe1	Reynold's Number, hot side		$dhV/\nu\mu$
(IP-128)	Ntui	Number of heat transfer units, hot side		↑
(IP-129)	C	Configuration factor		see text
(IP-130)	Nh	Number of hot flow strips		↓

Input No:	Entity:		Numerical Value:	Units:
(IP-131)	Nc	Number of cold flow strips		
(IP-132)	Fs	Shape factor		
(IP-133)	Rs	Face ares rstio		see text
(IP0134)	Rf	Flow ratio		
(IP-135)	Bx	External border dimension		inches
(IP-136)	By	External border dimension		inches
(IP-137)	B'	Internal border dimension		inches
(IP-138)	W4	Flow		lbs/sec
(IP-139)	CODE	Plste material		see note

Note.....For (IP-31-50-67-86-103-122 and 139),
Insert "1" for AL-1100-F, or
Insert "2" for AL-3003-F

APPENDIX II

HX-1 PROGRAM.....CALL HX(J) $_{j\,=\,1.0}$:

Inputs:

Call numerical values from APPENDIX I, Sections I and II.

Initial numerical assumptions:

Equa. No.	Initial value:
(4)	150.0
(5)	T14+10
(6)	1.02 P14
(13)	2.0
(35)	T16+10
(36)	.98 P16

Notes:

Readout last result of all equations marked with a star "*".
Do not stop machine at TEST 9.

HOT SIDE:

$$S = \sqrt{.906894 \, \frac{dh^2}{\sigma}} \qquad (1)^*$$

$$n = \frac{4\,\sigma}{\pi\, dh^2} \qquad (2)^*$$

$$Axi = \left| n \;\; \pi\, dh \;\; tp \right| + {}'' (1-\sigma) \qquad (3)^*$$

$$np = \text{assume} \qquad (4)^*$$

(Will be altered only by TEST 8)

$$T13 = \text{assume} \tag{5}^*$$
(Will be altered only by TEST 6)

$$P13 = \text{assume} \tag{6}^*$$
(Will be altered only by TEST 2)

LG-1

If $6 \leq T13 \leq 40$

$$\bar{\nu}\,13 = \left\{ \left[e^{\frac{2.765}{.03\left[\sqrt[3]{P13}/(T13/40)\right]}} \right] \left(\frac{T13}{P13} \right) \right\} \tag{7}$$

If $40 < T13 < \infty$

$$\bar{\nu}\,13 = 2.863092 \left(\frac{T13}{P13} \right) \tag{8}$$

$$\mu\,13 = 2.37888 \times 10^{-7}\ (T13)^{.643} \tag{9}$$

$$V13 = \frac{12\ NRe_1\ \bar{\nu}\,13\ \mu\,13}{dh} \tag{10}^*$$

$$ah_1 = \frac{144\ W_1\ \bar{\nu}\,13}{V13} \tag{11}^*$$

$$Af_1 = \frac{ah_1}{\sigma} \tag{12}^*$$

$$X = \text{assume} \tag{13}^*$$
(Will be altered only by TEST 1)

$$X' = X - (2\ Bx) \tag{14}^*$$

$$Y' = \frac{X}{Fs} - (2\ By) \tag{15}^{*}$$

$$Y'_1 = \frac{Y' - \left[(C-1)\ B' \right] - Nh}{2\ (C-1)} \tag{16}^{*}$$

$$Af_1 \text{ calculated} = Nh\ (X'\ Y'_1) \tag{17}$$

TEST 1
(17) must = (12) ±.001
If (17) > (12), reduce (13) and iterate from (13).
" " < " , increase " " " " ".

$$Y'_2 = Y'_1 \frac{Ra}{2} \tag{18}^{*}$$

$$Y'_3 = Y'_1 \cdot Ra \tag{19}^{*}$$

$$l_1 = \frac{Y'_1}{24} \tag{20}$$

$$l_2 = \frac{B'}{12} \tag{21}$$

$$l_3 = \frac{Y'_3}{12 \cdot Ra} \tag{22}$$

$$\Delta P'_1 = \frac{370 \times 10^{-6}\ V13^2}{\bar{\nu}\ 13} \sqrt{\frac{|tp/dh|}{NRe_1}} \tag{23}$$

$$\Delta P_l = np \cdot \Delta P'_l \qquad (24)^*$$

$$P13 \text{ calculated} = P14 + \Delta P_l \qquad (25)$$

TEST 2
(25) must = (6) ±.001
If (25) > (6), increase (6) and iterate from (6).
" " < " , reduce " " " " " .

$$\mu ml = \frac{8.55497 \times 10^{-4}}{(T13 - T14)} \left\{ \frac{\left[(T13)^{1.643} - (T14)^{1.643} \right]}{1.643} \right\} \qquad (26)$$

$$Kml = \frac{57.79 \times 10^{-3}}{[.00355\,(T13 - T14)]} \left\{ \frac{\left[(.00355\ T13)^{1.642} - (.00355\ T14)^{1.642} \right]}{1.642} \right\} \qquad (27)$$

$$Thm = \frac{\left(\dfrac{Kml}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \qquad (28)$$

$$Phm = \frac{(P13 + P14)}{2} \qquad (29)$$

Call cp subroutine and, with Thm and Phm.....get

(30)

cphm =

$$Chl = cphm \cdot Wl \qquad (31)^*$$

$$NPrl = \frac{cphm \cdot \mu\, ml}{Kml} \qquad (32)^*$$

$$N_{Nu_1} = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{N_{Re_1} \cdot N_{Pr_1}} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{N_{re_1} \cdot N_{pr_1}} \right]^{.8}} \right)} \right\} \tag{33}^{*}$$

$$h_{1\text{-}2} = \frac{N_{Nu_1} \cdot K_{m_1}}{dh} \tag{34}^{*}$$

COLD SIDE:

$$T17 = \text{assume} \tag{35}^{*}$$

(Will be altered only by TEST 5)

$$P17 = \text{assume} \tag{36}^{*}$$

(Will be altered only by TEST 3)

LG-2

If $6 \leq T17 \leq 40$

$$\bar{\nu}_{17} = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P17} / [T17/40]\right]}} \right] \left(\frac{T17}{P17} \right) \right\} \tag{37}$$

If $40 < T17 < \infty$

$$\bar{\nu}_{17} = 2.863092 \left(\frac{T17}{P17} \right) \tag{38}$$

$$ah_2 = ah_1 \cdot Ra \tag{39}^{*}$$

$$V17 = \frac{144 \; W_1 \quad \bar{\nu}_{17}}{ah_2} \tag{40}^{*}$$

$$\mu_{17} = 2.37888 \times 10^{-7} \, (T17)^{.643} \qquad (41)$$

$$NRe2 = \frac{V17 \cdot dh}{12 \ \bar{\rho}\, 17 \cdot \mu 17} \qquad (42)^{*}$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} \ V17^2}{\bar{\rho}\, 17} \sqrt{\frac{(tp/dh)}{NRe2}} \qquad (43)$$

$$\Delta P_2 = np \cdot \Delta P'_2 \qquad (44)^{*}$$

$$P17 \text{ calculated} = P16 - \Delta P2 \qquad (45)$$

TEST 3
(45) must = (36) ±.001
If (45) > (36), increase (36) and iterate from (36).
" " < " , reduce " " " " ".

TEST 4
If (45) < 10, stop & readout message.....INCREASE Ra "REDUCE NRe1, or "
" " ≥ ", continue.

$$\mu m2 = \frac{8.55497 \times 10^{-4}}{(T17 - T16)} \left\{ \left[\frac{(T17)^{1.643} - (T16)^{1.643}}{1.643} \right] \right\} \qquad (46)$$

$$Km2 = \frac{57.79 \times 10^{-3}}{\left[.00355 \, (T17 - (T16)\right]} \cdot \left\{ \frac{\left[(.00355 \, T17)^{1.642} - (.00355 \, T16)^{1.642} \right]}{1.642} \right\}$$

(47)

$$Tcm = \frac{\left(\frac{Km2}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \tag{48}$$

$$Pcm = \frac{(P16 + P17)}{2} \tag{49}$$

Call cp subroutine and, with Tcm and Pcm ...... get

$$cpcm = \tag{50}$$

$$Cc2 = cpcm \cdot W1 \tag{51*}$$

$$NPr2 = \frac{cpcm \cdot \mu\, m2}{Km2} \tag{52*}$$

$$NNu2 = 3.66 + \left\{ \frac{\left(\frac{\frac{.104}{(tp/dh)}}{NRe2 \cdot NPr2} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe2 \cdot NPr2} \right]^{.8}} \right)} \right\} \tag{53*}$$

$$h_{5-6} = \frac{12 \ NNu_2 \cdot Km_2}{dh} \qquad (54)^*$$

LG - 3

If $Ch_1 < Cc_2$ go to (55)

If $Ch_1 > Cc_2$ go to (61)

If $Ch_1 \equiv Cc_2 \pm 10^{-6}$ go to (67)

$\boxed{\text{If } Ch_1 < Cc_2}$

$$\nabla_1 = (T14 - T16) \ e^{Ntu_1 \left[1-(Ch_1/Cc_2)\right]} \qquad (55)$$

$$\Delta X = \frac{\nabla_1 - (T14 - T16)}{\left(\frac{Cc_2}{Ch_1}\right) - 1} \qquad (56)$$

$$\Delta Y = \left(\frac{Cc_2}{Ch_1}\right) \cdot \Delta X \qquad (57)$$

$$T17 \text{ calculated} = T16 + \Delta X \qquad (58)$$

TEST 5-A
(58) must = (35) ±.001
If (58) > (35), increase (35) and iterate from (35).
" " < " , reduce " " " " " .

$$T13 \text{ calculated} = T14 + \Delta Y \tag{59}$$

TEST 6-A
(59) must = (5) ±.001
If (59) > (5), increase (5) and iterate from (5).
" " < " , reduce " " " " " .

$$\epsilon i = \frac{1-e^{-Ntui\left[1-\left(Ch1/Cc2\right)\right]}}{1-\left\{\left(\frac{Ch1}{Cc2}\right)e^{-Ntui\left[1-\left(Ch1/Cc2\right)\right]}\right\}} \tag{60*}$$

Then go to (71)

$$\boxed{\text{If } Ch1 > Cc2}$$

$$\nabla 1 = (T14 - T16)\, e^{Ntui\left[1-\left(Cc2/Ch1\right)\right]} \tag{61}$$

$$\Delta X = \frac{\nabla 1 - (T14 - T16)}{\left(\frac{Ch1}{Cc2}\right) - 1} \tag{62}$$

$$\Delta Y = \left(\frac{Ch1}{Cc2}\right) \cdot \Delta X \tag{63}$$

$$T17 \text{ calculated} = T16 + \Delta X \tag{64}$$

TEST 5-B
(64) must = (35) ±.001
If (64) > (35), increase (35) and iterate from (35).
" " < " ,reduce " " " " " .

$$T13 \text{ calculated} = T14 + \Delta Y \tag{65}$$

TEST 6-B
(65) must = (5) ±.001
If (65) > (5), increase (5) and iterate from (5).
" " < " , reduce " " " " " .

$$\epsilon i = \frac{1 - e^{-Ntui\left[1-\left(Cc2/Chi\right)\right]}}{1-\left\{\left(\frac{Cc2}{Chi}\right) e^{-Ntui\left[1-\left(Cc2/Chi\right)\right]}\right\}} \tag{66*}$$

Then go to (71)

$$\boxed{\text{If } Chi \equiv Cc2 \pm 10^{-6}}$$

$$Z = \frac{(T14 - T16)}{1 - \left(\frac{Ntui}{1 + Ntui}\right)} \tag{67}$$

$$T17 \text{ calculated} = (T16 + Z) - (T14 - T16) \tag{68}$$

TEST 5-C
(68) must = (35) ±.001
If (68) > (35), increase (35) and iterate from (35).
" " < " , reduce " " " " " .

$$T13 \text{ calculated} = T16 + Z \tag{69}$$

TEST 6-C
(69) must = (5) ±.001
If (69) > (5), increase (5) and iterate from (5).
" " < " , reduce " " " " " .

$$\epsilon i = \frac{Ntui}{1 + Ntui} \qquad (70)^*$$

Then go to (71)

$$T'_1 = Thm - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \qquad (71)$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \qquad (72)$$

LG-4

If (1P - 31) CODE = 1.0
to to LG-5

If (1P - 31) CODE = 2.0
to to LG-6

LG-5

If $0 < Thm \leq 113$ go to (73)

If $113 < Thm \leq 540$ go to (74)

If $540 < Thm < \infty$ go to (75)

$$Kp = \frac{1}{[.1\,(Thm - T'_1)]}\left\{\frac{49}{2}\left[(.1\,Thm)^2 - (.1\,T'_1)^2\right] - \frac{1}{3.47}\left[(.1\,Thm)^{3.47} - (.1\,T'_1)^{3.47}\right]\right\} \tag{73}$$

Then go to (79)

$$Kp = \frac{1}{[.1\,(Thm - T'_1)]}\left\{\left[-\frac{\left[(.1\,Thm)^{2.708} - (.1\,T'_1)^{2.708}\right]}{2.708}\right] + \left[9.551\left[(.1\,Thm)^2 - (.1\,T'_1)^2\right]\right]\right\} \tag{74}$$

Then go to (79)

$$Kp = 111.74 = \text{constant} \tag{75}$$

Then go to (79)

LG-6

If $0 < Thm \leq 210$ go to (76)

If $210 < Thm \leq 540$ go to (77)

If $540 < Thm < \infty$ go to (78)

$$Kp = \frac{1}{(Thm - T'_1)}\left\{\left[\frac{2.765}{2}\left[(Thm)^2 - (T'_1)^2\right]\right] - \left[\frac{\left[(Thm)^{2.16} - (T'_1)^{2.16}\right]}{2.16}\right]\right\} \tag{76}$$

Then go to (79)

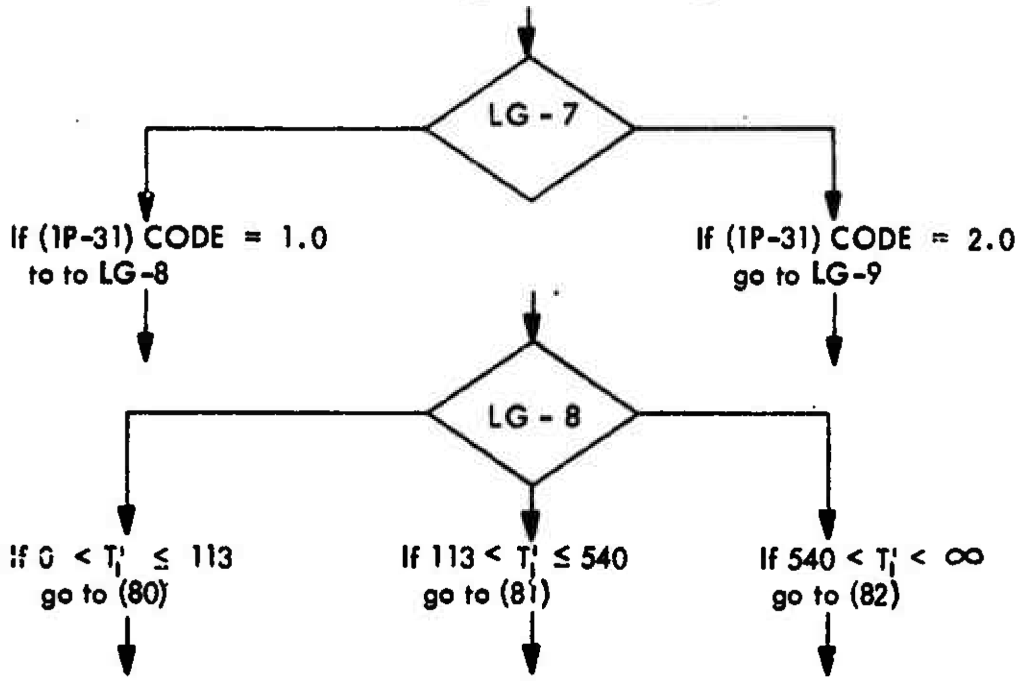
$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(Thm + T'_1)/2 \right] - 210}{330} \right) \right\} \tag{77}$$

Then go to (79)

$$Kp = 92.25 = \text{constant} \tag{78}$$

Then go to (79)

$$\underset{2-3}{K} = Kp \ .93061 \left[\frac{s - dh}{s - \left({dh}/{2} \right)} \right] \tag{79*}$$



$$Kp = \frac{1}{\left[.1 \left(T_1' - T_2' \right) \right]} \left\{ \frac{49}{2} \left[(.1\, T_1')^2 - (.1 T_2')^2 \right] - \frac{1}{3.47} \left[(.1\, T_1')^{3.47} - (.1\, T_2')^{3.47} \right] \right\}$$

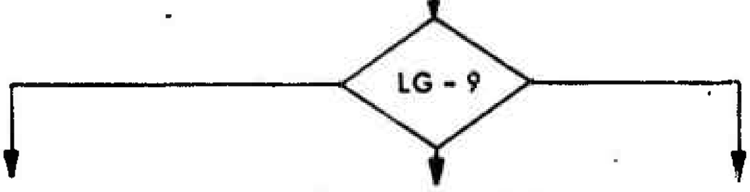
Then go to (86) (80)

$$K_p = \frac{1}{\left[.1\,(T_1' - T_2')\right]}\left\{\left[-\frac{(.1\,T_1')^{2.708} - (.1\,T_2')^{2.708}}{2.708}\right] + \left[9.551\,\left[(.1T_1')^2 - (.1T_2')^2\right]\right]\right\} \tag{81}$$

Then go to (86)

$$K_p = 111.74 = \text{constant} \tag{82}$$

Then go to (86)



If $0 < T_1' \leq 210$ go to (83)

If $210 < T_1' \leq 540$ go to (84)

If $540 < T_1' < \infty$ go to (85)

$$K_p = \frac{1}{(T_1' - T_2')}\left\{\frac{2.765}{2}\left[(T_1')^2 - (T_2')^2\right] - \left[\frac{(T_1')^{2.16} - (T_2')^{2.16}}{2.16}\right]\right\} \tag{83}$$

Then go to (86)

$$K_p = 86.0 + \left\{6.25\left(\frac{\left[(T_1') + T_2')/2\right] - 210}{330}\right)\right\} \tag{84}$$

Then go to (86)

$$K_p = 92.25 = \text{constant} \tag{85}$$

Then go to (86)

$K_{3-4} = Kp$ (86)*

LG - 10

If (1P - 31) CODE = 1.0 go to LG - 11

If (1P - 31) CODE = 2.0 go to LG - 12

LG - 11

If $0 < T_{\frac{1}{2}} \leq 113$ go to (87)

If $113 < T_{\frac{1}{2}} \leq 540$ go to (88)

If $540 < T_{\frac{1}{2}} < \infty$ go to (89)

$$Kp = \frac{1}{\left[.1\,(T_{\frac{1}{2}} - Tcm)\right]} \left\{ \frac{49}{2} \left[(.1\,T_{\frac{1}{2}})^{2} - (.1\,Tcm)^{2} \right] - \frac{1}{3.47} \left[(.1\,T_{\frac{1}{2}})^{3.47} - (.1\,Tcm)^{3.47} \right] \right\} \tag{87}$$

Then go to (93)

$$Kp = \frac{1}{\left[.1\,(T'_{2} - Tcm)\right]} \left\{ \left[- \frac{(.1\,T'_{2})^{2.708} - (.1\,Tcm)^{2.708}}{2.708} \right] + \left[9.551 \left[(.1\,T'_{2})^{2} - (.1\,Tcm)^{2} \right] \right] \right\} \tag{88}$$

Then go to (93)

$$Kp = 111.74 = \text{constant} \tag{89}$$

Then go to (93)

LG - 12

If $0 < T_2' \leq 210$ go to (90)

If $210 < T_2' \leq 540$ go to (91)

If $540 < T_2' < \infty$ go to (92)

$$K_p = \frac{1}{(T_2' - T_{cm})}\left\{\left[\frac{2.765}{2}\left[(T_2')^2 - (T_{cm})^2\right]\right] - \left[\frac{(T_2')^{2.16} - (T_{cm})^{2.16}}{2.16}\right]\right\} \qquad (90)$$

Then go to (93)

$$K_p = 86.0 + \left\{6.25\left(\frac{\left[(T_2') + T_{cm})/2\right] - 210}{330}\right)\right\} \qquad (91)$$

Then go to (93)

$$K_p = 92.25 = \text{constant} \qquad (92)$$

Then go to (93)

$$K_{4-5} = K_p\ .93061\left[\frac{s - dh}{s - (dh/2)}\right] \qquad (93)^*$$

$$U = \frac{1}{\frac{1}{h_{1-2}} + \frac{l_1}{K_{2-3}} + \frac{l_2}{K_{3-4}} + \frac{l_3}{K_{4-5}} + \frac{1}{h_{5-6}}} \qquad (94)^*$$

$$ns = np + 1 \qquad (95)^*$$

$$l_e = \frac{ns \cdot ts}{12} \qquad (96)$$

$$T\ell_1 = \frac{(T14 + (T16)}{2} \tag{97}$$

$$T\ell_2 = \frac{(T13 + T17)}{2} \tag{98}$$

$$Ak\ell = \frac{\left[(X^2/Fs) - (X'Y')\right] + \left[(C-1)\,X'\,B'\right]}{144} \tag{99}$$

$$\overline{K\ell} = \frac{7.27 \times 10^{-3}}{(T\ell_2 - T\ell_1)} \left[\frac{(T\ell_2)^{1.585} - (T\ell_1)^{1.585}}{1.585}\right] \tag{100}$$

$$Q\ell = \frac{\overline{K\ell} \cdot Ak\ell}{\ell e} \qquad (101)^*$$

LG - 13

If $Ch_1 < Cc_2$ go to (102)

If $Ch_1 > Cc_2$ go to (105)

If $Ch_1 \equiv Cc_2 \pm 10^{-6}$ go to (108)

If $Ch_1 < Cc_2$

$$\lambda = \frac{Q\ell}{3600\ Ch_1} \qquad (102)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (103)^*$$

TEST 7-A
If (103) ≥ 1.0, stop & readout message ..... "REDUCE Ntui"
" " < " , continue.

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left(Ch_1 / Cc_2 \right)}{1 - \epsilon} \right]}{1 - \left(\dfrac{Ch_1}{Cc_2} \right)} \qquad (104)^*$$

Then go to LG-14

$\boxed{\text{If } Ch_1 > Cc_2}$

$$\lambda = \frac{Ql}{3600 \quad Cc_2} \qquad (105)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (106)^*$$

TEST 7-B
If (106) ≥ 1.0, stop & readout message ..... "REDUCE Ntui"
" " < " , continue.

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left(Cc_2 / Ch_1 \right)}{1 - \epsilon} \right]}{1 - \left(\dfrac{Cc_2}{Ch_1} \right)} \qquad (107)^*$$

Then go to LG-14

$$\boxed{\text{If } Ch_1 \equiv Cc_2 \quad \pm 10^{-6}}$$

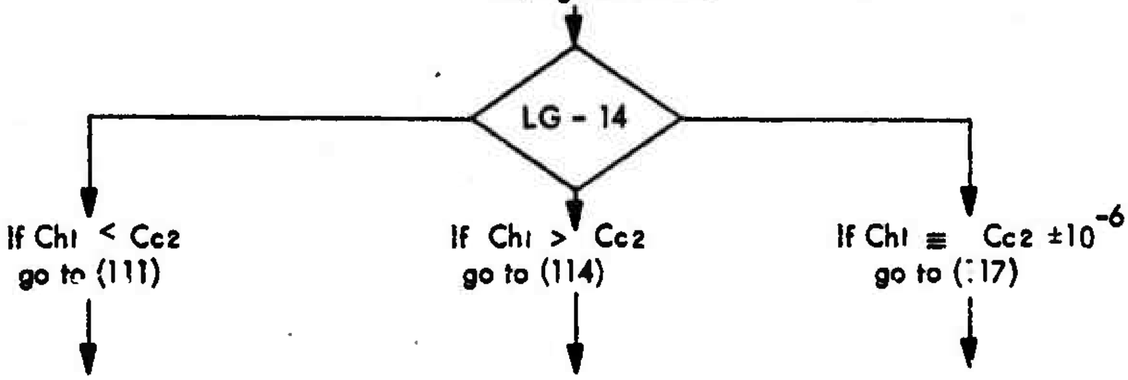
$$\lambda = \frac{Q\,\ell}{3600\ Ch_1} \qquad (108)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1-\lambda} \right) \qquad (109)^*$$

TEST 7-C
If (109) $\geq$ 1.0, stop & readout message ..... "REDUCE Ntu_i"
" " < " , continue.

$$Ntu = \frac{\epsilon}{1-\epsilon} \qquad (110)^*$$

Then go to LG-14



$$\boxed{\text{If } Ch_1 < Cc_2}$$

$$Ax\ \text{tot. hot side} = \frac{3600\ Ntu\ \ Ch_1}{U} \qquad (111)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (112)^*$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{\text{Axp}} \tag{113}$$

Note ..... If a fraction results, go to next higher whole number.

TEST 8-A

(113) must = (4) $^{+1}_{-0}$

If (113) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " ".

Then go to (120)

$$\boxed{\text{If } Ch_1 > Cc_2}$$

$$\text{Ax tot. hot side} = \frac{3600 \text{ Ntu } Cc_2}{U} \tag{114*}$$

$$Axp = Ax_1 \cdot Af_1 \tag{115*}$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{\text{Axp}} \tag{116}$$

Note.... If a fraction results, go to next higher whole number.

TEST 8-B

(116) must = (4) $^{+1}_{-0}$

If (116) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " " ".

Then go to (120)

$$\boxed{\text{If } C_{h1} \equiv C_{c2} \quad \pm 10^{-6}}$$

$$\text{Ax tot. hot side} = \frac{3600 \; Ntu \; C_{h1}}{U} \tag{117*}$$

$$Axp = Ax_1 \cdot Af_1 \tag{118*}$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{Axp} \tag{119}$$

Note..... If a fraction results, go to next higher whole number.

TEST 8-C
(119) must = (4) $^{+1}_{-0}$
If (119) > (4), increase (4) and iterate from (4).
" " < " , reduce " " " " ".

Then go to (120)

$$\text{width } X = \text{equation (13) after closure} = \text{inches} \tag{120*}$$

$$\text{height } Y = \frac{X}{Fs} = \text{inches} \tag{121*}$$

$$\text{core length } L = \left[(np \cdot tp) + (ns \cdot ts)\right] = \text{inches} \tag{122*}$$

$$\text{core weight} = .098\ np\ tp \left\{ \left[(XY) - (X'\ Y') \right] + \left[X'\ B'\ (C-1) \right] + \left[Af_I\ (Ro + 1)\ (1 - \sigma) \right] \right\} +$$

$$.078\ ns\ ts \left\{ \left[(XY) - (X'\ Y') \right] + \left[X'\ B'\ (C-1) \right] \right\} = \text{lbs} \qquad (123)^*$$

$$\text{header weight} = .196 \left[(XY) - Af_I\ (Ro + 1) + \frac{XY}{8} \right] = \text{lbs} \qquad (124)^*$$

$$\text{total weight} = (123) + (124) = \text{lbs} \qquad (125)^*$$

$$\eta_f = \frac{1}{1 + \left[\dfrac{h_{1-2} \left({}^{Axp}/_{Nh} \cdot Y'_I \right) (Y'_I)^2}{3\ np\ K_{2-3} \left\{ X'\ tp\ .93061 \left[\dfrac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \qquad (126)^*$$

TEST 9

if (126) < .40, readout message .... "INCREASE (1P-24)."

" " > .60, readout message .... "REDUCE " ."

Do not stop machine on TEST 9.

$$Av = \frac{Ax\ \text{tot. hot side}}{\left(\dfrac{X \cdot Y \cdot L}{1728} \right)} = ft^2 / ft^3 \qquad (127)^*$$

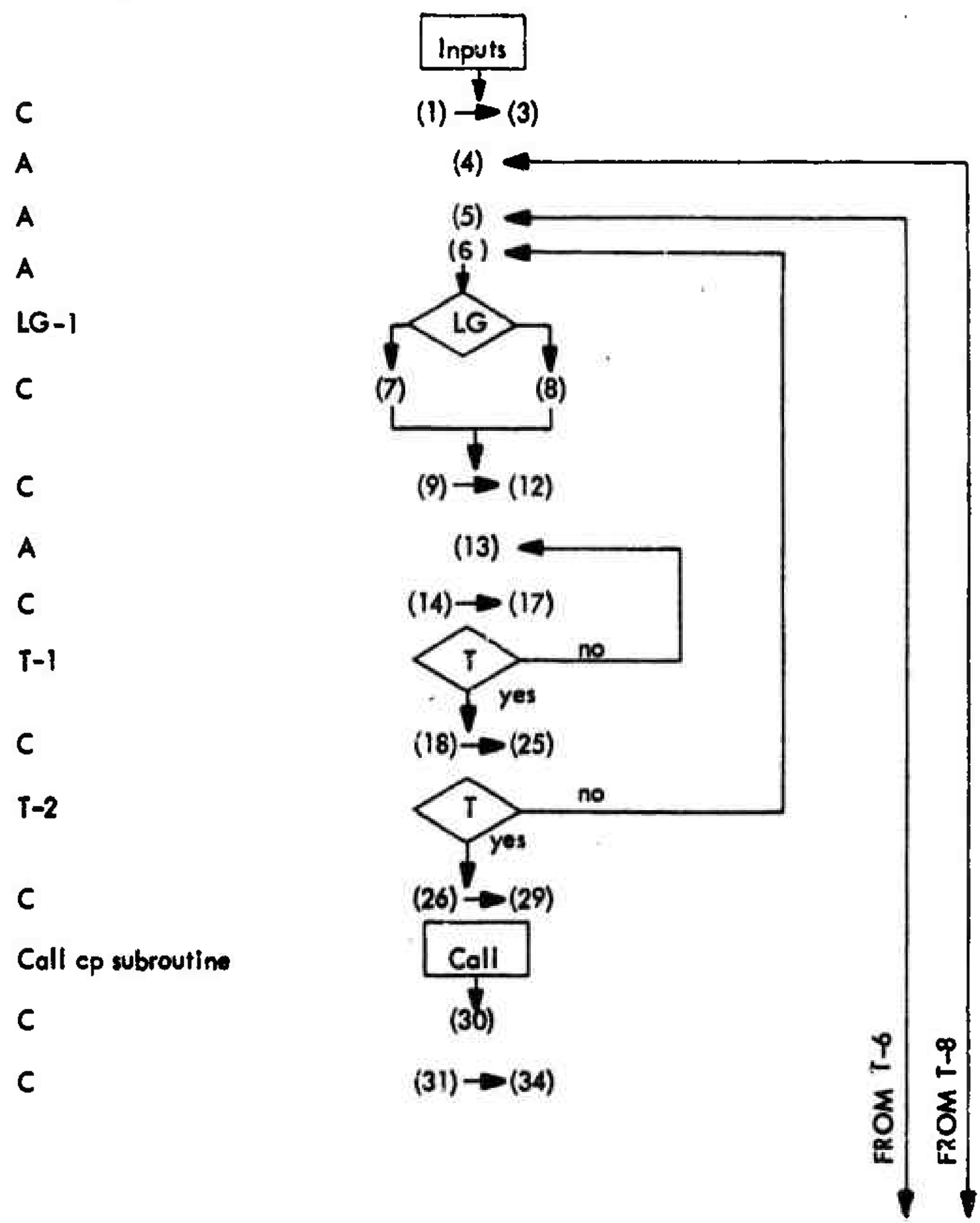
FINAL TEST

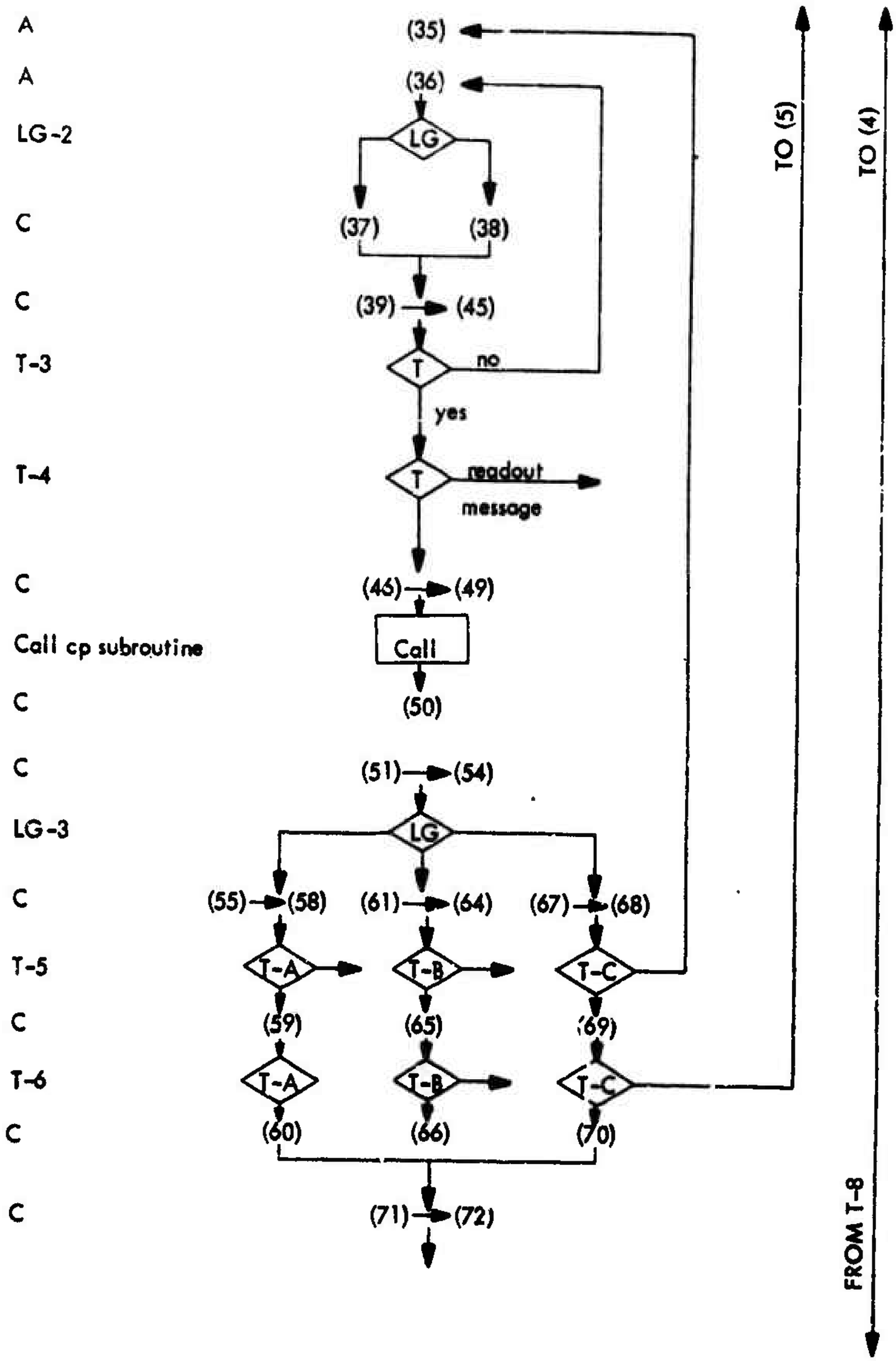
If (35) $\geq$ 540, stop machine.

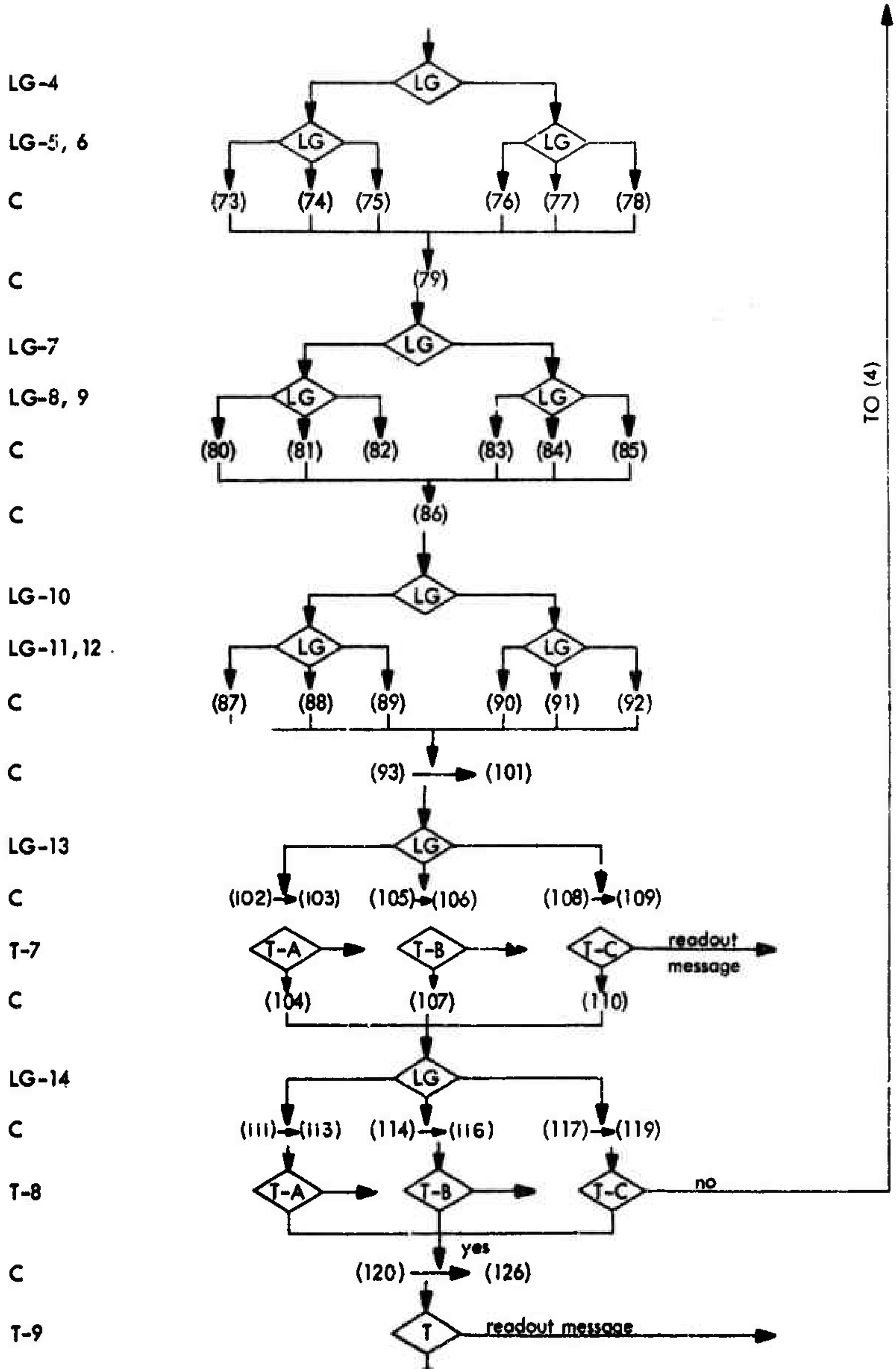
" " < ", call HX (J) J = 2.0 and continue.

FLOW DIAGRAM FOR HX-1

A = assume
C = compute
LG = logic gate
T = test




A
A
LG-2
C
C
T-3
T-4
C
Call cp subroutine
C
C
LG-3
C
T-5
C
T-6
C
C
(35)
(36)
LG
(37)
(38)
(39)
(45)
T
no
yes
T
readout
message
(46)
(49)
Call
(50)
(51)
(54)
LG
(55)
(58)
(61)
(64)
(67)
(68)
T-A
T-B
T-C
(59)
(65)
(69)
T-A
T-B
T-C
(60)
(66)
(70)
(71)
(72)
TO (5)
TO (4)
FROM T-8


LG-4
LG-5, 6
C
C
LG-7
LG-8, 9
C
C
LG-10
LG-11, 12
C
C
LG-13
C
T-7
C
LG-14
C
T-8
C
T-9
LG
(73)
(74)
(75)
(76)
(77)
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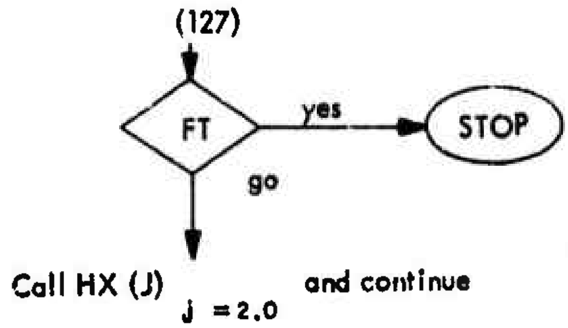
(93)
(101)
(102)
(103)
(105)
(106)
(108)
(109)
T-A
T-B
T-C
readout message
(104)
(107)
(110)
(111)
(113)
(114)
(116)
(117)
(119)
no
yes
(120)
(126)
T
readout message
TO (4)

C

Final Test



APPENDIX III

HX-2 AND TURBINE 1 PROGRAM ..... CALL HX (J) $_j = 2.0$'

Inputs:

Call numerical values from APPENDIX I, Section III.
Also call last result for T13, P13, T17 and P17 from output of HX-1.

Initial numerical assumtions:

Eqa. No:	Initial value:
(4)	30.0
(5)	T13 + 5
(6)	1.02 P13
(13)	2.0
(41)	T17 + 5
(42)	.98 P17

Notes:

Readout last result of all equations marked with a star "*"
Do not stop machine for TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \quad \frac{dh^2}{\sigma}} \qquad (1)^*$$

$$n = \frac{4\sigma}{\pi dh^2} \qquad (2)^*$$

$$Ax_1 = (n \; \pi dh \; tp) + 2\,(1-\sigma) \qquad (3)^*$$

np = assume
(Will be altered only by TEST 8) (4)*

T12 = assume
(Will be altered only by TEST 3) (5)*

P12 = assume
(Will be altered only by TEST 2) (6)*

LG-1

If $6 \leq T12 \leq 40$

$$\bar{\nu}_{12} = \left\{\left[\frac{2.765}{e^{.03\left[\sqrt[3]{P12}\,/\,(T12/10)\right]}}\right]\left(\frac{T12}{P12}\right)\right\} \qquad (7)$$

If $40 < T12 < \infty$

$$\bar{\nu}_{12} = 2.863092 \left(\frac{T12}{P12}\right) \qquad (8)$$

$$\mu_{12} = 2.37888 \times 10^{-7}\,(T12)^{.643} \qquad (9)$$

$$V12 = \frac{12 \ N_{re1} \ \bar{\nu}_{12} \ \mu_{12}}{dh} \qquad (10)^*$$

$$ah_1 = \frac{144 \ W1 \ \bar{\nu}_{12}}{V12} \qquad (11)^*$$

$$Af_1 = \frac{ah_1}{\sigma} \qquad (12)^*$$

$$X = \text{assume} \qquad (13)^*$$

(Will be altered only by TEST 1)

$$X' = X - (2\ Bx) \qquad (14)^*$$

$$Y' = \frac{X}{Fs} - (2\ By) \qquad (15)^*$$

$$Y_1' = \frac{Y' - \left[(C-1) B' \right] - Nh}{2\ (C-1)} \qquad (16)^*$$

$$Af_1 \text{ calculated} = Nh\ (X'\ Y_1') \qquad (17)$$

TEST 1
(17) must = (12) ±.001
If (17) > (12), reduce (13) and iterate from (13).
" " < " , increase " " " " " .

$$Y'_2 = Y'_1 \frac{Ra}{2} \tag{18)*}$$

$$Y'_3 = Y'_1 \cdot Ra \tag{19)*}$$

$$l_1 = \frac{Y'_1}{24} \tag{20}$$

$$l_2 = \frac{B'}{12} \tag{21}$$

$$l_3 = \frac{Y'_3}{12 \cdot Ra} \tag{22}$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} \quad V12^2}{\bar{\nu}\, 12} \sqrt{\frac{(tp/dh)}{NRe_1}} \tag{23}$$

$$\Delta P_1 = np \cdot \Delta P'_1 \tag{24)*}$$

$$P12 \text{ calculated} = P13 + \Delta P_1 \tag{25}$$

TEST 2
(25) must = (6) ±.001
If (25) > (6), increase (6) and iterate from (6).
" " < " , reduce " " " " ".

Call cp subroutine and, with T12 and P12 .... get

cp12 = (26)

Call cp subroutine and, with T17 and P17 ..... get

$$cp17 = \tag{27}$$

$$\overline{cp} = \frac{(cp12 + cp17)}{2} \tag{28}$$

$$\bar{\gamma} = \frac{1}{1 - \left(\frac{.496447487}{\overline{cp}}\right)} \tag{29}$$

$$\frac{T17}{T12} = 1 - \eta t \left[1 - \left({}^{P17}/_{P12} \right)^{(\bar{\gamma}-1)/\bar{\gamma}} \right] \tag{30}$$

$$\text{T12 calculated} = \frac{T17}{(T17/T12)} \tag{31}$$

TEST 3
(31) must = (5) ±.001
If (31) > (5), Increase (5) and iterate from (5).
" " < " , reduce " " " " " .

$$\mu m_l = \frac{8.55497 \times 10^{-4}}{(T12 - T13)} \left\{ \frac{(T12)^{1.643} - (T13)^{1.643}}{1.643} \right\} \tag{32}$$

$$K_{mI} = \frac{57.79 \times 10^{-3}}{\left[.00355\,(T12 - T13)\right]} \left\{ \frac{\left[(.00355\,T12)^{1.642} - (.00355\,T13)^{1.642}\right]}{1.642} \right\} \quad (33)$$

$$Thm = \frac{\left(\dfrac{K_{mI}}{57.79 \times 10^{-3}}\right)^{1/.642}}{.00355} \quad (34)$$

$$Phm = \frac{(P12 + P13)}{2} \quad (35)$$

Call cp subroutine and, with Thm and Phm.....get

$$cphm = \quad (36)$$

$$Ch_I = cphm \cdot W_I \quad (37)^*$$

$$NPr_I = \frac{cphm \cdot \mu m_I}{K_{mI}} \quad (38)^*$$

$$NNu_I = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{NRe_I \cdot NPr_I}\right]}\right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{NRe_I \cdot NPr_I}\right]^{.8}}\right)} \right\} \quad (39)^*$$

$$h_{1-2} = \frac{12\ NNu_1 \cdot Km_1}{dh} \tag{40}^*$$

COLD SIDE:

$$T18 = \text{assume} \tag{41}^*$$

(Will be altered only by TEST 6)

$$P18 = \text{assume} \tag{42}^*$$

(Will be altered only by TEST 4)

LG-2

If $6 \leq T18 \leq 40$

If $40 < T18 < \infty$

$$\bar{\nu}_{18} = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P18}\,/\left(T18/40\right)\right]}} \right] \left(\frac{T18}{P18} \right) \right\} \tag{43}$$

$$\bar{\nu}_{18} = 2.863092 \left(\frac{T18}{P18} \right) \tag{44}$$

$$\mu_{18} = 2.37888 \times 10^{-7}\ (T18)^{.643} \tag{45}$$

$$ah_2 = ah_1 \cdot Ro \tag{46}^*$$

$$V18 = \frac{144\ W_2\ \bar{\nu}_{18}}{ah_2} \tag{47}^*$$

$$NRe_2 = \frac{V18 \cdot dh}{12\ \bar{\nu}_{18} \cdot \mu_{18}} \tag{48}^*$$

$$\Delta P_2' = \frac{370 \times 10^{-6} \; V_{18}^{\;2}}{\bar{\nu}_{18}} \sqrt{\frac{(tp/dh)}{NRe_2}} \tag{49}$$

$$\Delta P_2 = np \cdot \Delta P_2' \qquad (50)^*$$

$$P18 \text{ calculated} = P17 - \Delta P_2 \tag{51}$$

TEST 4
(51) must = [illegible] ±.001
If (51) > (42), increase (42) and iterate from (42).
" " < " , reduce " " " " " .

TEST 5
If (51) < 10, stop & readout message ....."INCREASE Ra"
" " ≥ " , continue.

$$\mu m_2 = \frac{8.55497 \times 10^{-4}}{(T18 - T17)} \left\{ \frac{\left[(T18)^{1.643} - (T17)^{1.643}\right]}{1.643} \right\} \tag{52}$$

$$Km_2 = \frac{57.79 \times 10^{-3}}{[.00355\,(T18 - T17)]} \left\{ \frac{\left[(.00355\; T18)^{1.642} - (.00355\; T17)^{1.642}\right]}{1.642} \right\} \tag{53}$$

$$Tcm = \frac{\left(\dfrac{Km_2}{57.79 \times 10^{-3}}\right)^{1/.642}}{.00355} \tag{54}$$

$$Pcm = \frac{(P17 + P18)}{2} \tag{55}$$

Call cp subroutine and, with Tcm and Pcm.....get

$$cpcm = \qquad (56)$$

$$Cc2 = cpcm \cdot W2 \qquad (57)^{*}$$

$$NPr2 = \frac{cpcm \cdot \mu m2}{Km2} \qquad (58)^{*}$$

$$NNu2 = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]^{.8}} \right)} \right\} \qquad (59)^{*}$$

$$h_{5-6} = \frac{12 \; NNu2 \cdot Km2}{dh} \qquad (60)^{*}$$

LG-3

If Ch1 < Cc2 go to (61)

If Ch1 > Cc2 go to (64)

If Ch1 ≡ Cc2 $\pm 10^{-6}$ go to (67)

$$\boxed{\text{If } C_{h1} < C_{c2}}$$

$$T18 \text{ calculated} = T17 + \left[\frac{(T12 - T13)}{(C_{c2}/C_{h1})}\right] \tag{61}$$

TEST 6-A
(61) must = (41) ±.001
If (61) > (41), increase (41) and iterate from (41).
" " < " , reduce " " " " " .

$$N_{tui} = \frac{\log_e \left[\frac{(T12 - T18)}{(T13 - T17)}\right]}{1 - \left(C_{h1}/C_{c2}\right)} \tag{62*}$$

$$\epsilon_i = \frac{1 - e^{-N_{tui}\left[1 - \left(C_{h1}/C_{c2}\right)\right]}}{1 - \left\{\left(\frac{C_{h1}}{C_{c2}}\right) e^{-N_{tui}\left[1 - \left(C_{h1}/C_{c2}\right)\right]}\right\}} \tag{63*}$$

Then go to (70)

$$\boxed{\text{If } C_{h1} > C_{c2}}$$

$$T18 \text{ calculated} = T17 + \left[\frac{(T12 - T13)}{(C_{h1}/C_{c2})}\right] \tag{64}$$

TEST 6-B
(64) must = (41) ±.001
If (64) > (41), increase (41) and iterate from (41).
" " < " , reduce " " " " " .

$$N_{tui} = \frac{\log_e \left[\frac{(T12 - T18)}{(T13 - T17)}\right]}{1 - \left(C_{c2}/C_{h1}\right)} \tag{65*}$$

$$\epsilon i = \frac{1 - e^{-Ntui\left[1 - \left(Cc2/Ch1\right)\right]}}{1 - \left\{\left(\frac{Cc2}{Ch1}\right) e^{-Ntui\left[1 - \left(Cc2/Ch1\right)\right]}\right\}} \qquad (66)^*$$

Then go to (70)

$\boxed{\text{If } Ch1 \equiv Cc2 \pm 10^{-6}}$

$$T18 \text{ calculated} = T12 - (T13 - T17) \qquad (67)$$

TEST 6-C
(67) must = (41) ±.001
If (67) > (41), increase (41) and iterate from (41).
" " < " , reduce " " " " " .

$$Ntui = \frac{\left[\frac{(T12 - T13)}{(T12 - T17)}\right]}{1 - \left[\frac{(T12 - T13)}{(T12 - T17)}\right]} \qquad (68)^*$$

$$\epsilon i = \frac{Ntui}{1 + Ntui} \qquad (69)^*$$

Then go to (70)

$$T'_1 = Thm - \left[\left(\frac{Y'}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \tag{70}$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \tag{71}$$

LG - 4

If (1P-50) CODE = 1.0
go to LG - 5

If (1P-50) CODE = 2.0
go to LG - 6

LG - 5

If $0 < Thm \leq 113$
go to (72)

If $113 < Thm \leq 540$
go to (73)

If $540 < Thm < \infty$
go to (74)

$$Kp = \frac{1}{\left[.1\,(Thm - T'_1) \right]} \left\{ \frac{49}{2} \left[(.1\ Thm)^2 - (.1\ T'_1)^2 \right] - \frac{1}{3.47} \left[(.1\ Thm)^{3.47} - (.1\ T'_1)^{3.47} \right] \right\} \tag{72}$$

Then go to (78)

$$Kp = \frac{1}{\left[.1\,(Thm - T'_1) \right]} \left\{ - \left[\frac{(.1\ Thm)^{2.708} - (.1\ T'_1)^{2.708}}{2.708} \right] + \left[9.551 \left[(.1\ Thm)^2 - (.1\ T'_1)^2 \right] \right] \right\} \tag{73}$$

Then go to (78)

$$Kp = 111.74 = \text{constant} \tag{74}$$

Then go to (78)

LG - 6

If 0 < Thm ≤ 210
go to (75)

If 210 < Thm ≤ 540
go to (76)

If 540 < Thm < ∞
go to (77)

$$Kp = \frac{1}{(Thm - T'_1)} \left\{ \frac{2.765}{2} \left[(Thm)^2 - (T'_1)^2 \right] - \left[\frac{\left[(Thm)^{2.16} - (T'_1)^{2.16} \right]}{2.16} \right] \right\} \qquad (75)$$

Then go to (78)

$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(Thm + T'_1) / 2 \right] - 210}{330} \right) \right\} \qquad (76)$$

Then go to (78)

$$Kp = 92.25 = \text{constant} \qquad (77)$$

Then go to (78)

$$K_{2-3} = Kp \ .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \qquad (78)^*$$

LG - 7

If (1P-50) CODE = 1.0
go to LG - 8

If (1P-50) CODE = 2.0
go to LG-9

LG - 8

If $0 < T'_1 \leq 113$ go to (79)

If $113 < T'_1 \leq 540$ go to (80)

If $540 < T'_1 < \infty$ go to (81)

$$K_p = \frac{1}{\left[.1\,(T'_1 - T'_2)\right]} \left\{ \frac{49}{2} \left[(.1\,T'_1)^2 - (.1\,T'_2)^2 \right] - \frac{1}{3.47} \left[(.1\,T'_1)^{3.47} - (.1\,T'_2)^{3.47} \right] \right\} \tag{79}$$

Then go to (85)

$$K_p = \frac{1}{\left[.1(T'_1 - T'_2)\right]} \left\{ - \left[\frac{(.1\,T'_1)^{2.708} - (.1\,T'_2)^{2.708}}{2.708} \right] + 9.551 \left[(.1\,T'_1)^2 - (.1\,T'_2)^2 \right] \right\} \tag{80}$$

Then go to (85)

$$K_p = 111.74 = \text{constant} \tag{81}$$

Then go to (85)

LG - 9

If $0 < T'_1 \leq 210$ go to (82)

If $210 < T'_1 \leq 540$ go to (83)

If $540 < T'_1 < \infty$ go to (84)

$$K_p = \frac{1}{(T'_1 - T'_2)}\left\{\frac{2.765}{2}\left[(T'_1)^2 - (T'_2)^2\right] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16}\right]\right\} \tag{82}$$

Then go to (85)

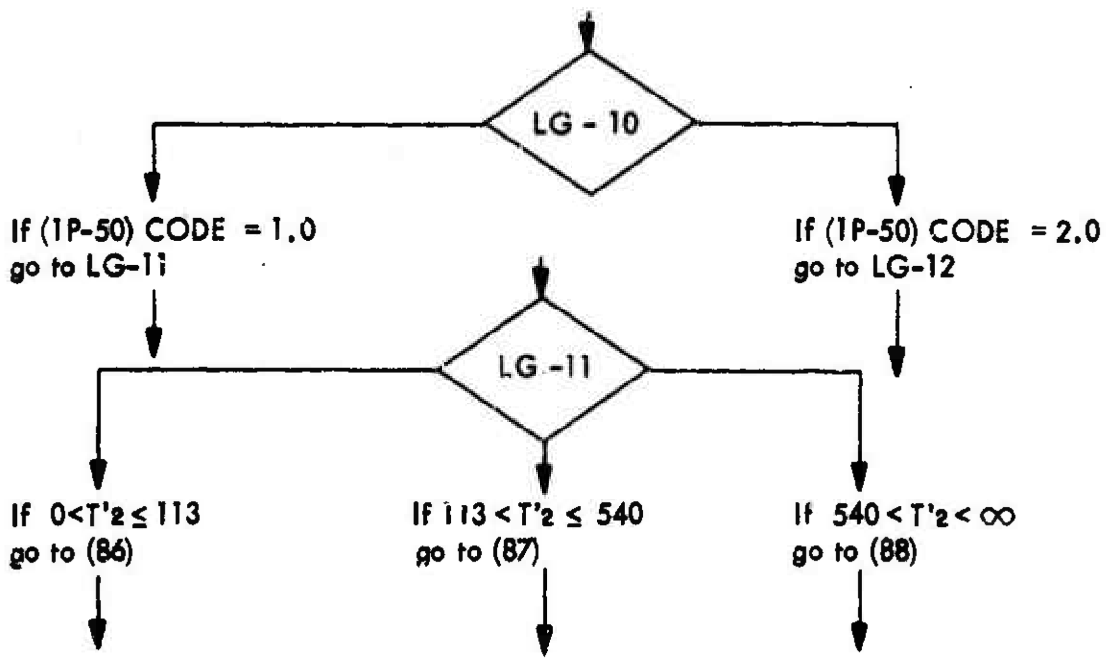
$$K_p = 86.0 + \left\{6.25\left(\frac{\left[(T'_1 + T'_2)/2\right] - 210}{330}\right)\right\} \tag{83}$$

Then go to (85)

$$K_p = 92.25 = \text{constant} \tag{84}$$

Then go to (85)

$$K_{3-9} = K_p \tag{85}$$



$$K_p = \frac{1}{\left[.1\,(T'_2 - T_{cm})\right]}\left\{\frac{49}{2}\left[(.1\,T'_2)^2 - (.1\,T_{cm})^2\right] - \frac{1}{3.47}\left[(.1\,T_2)^{3.47} - (.1\,T_{cm})^{3.47}\right]\right\} \tag{86}$$

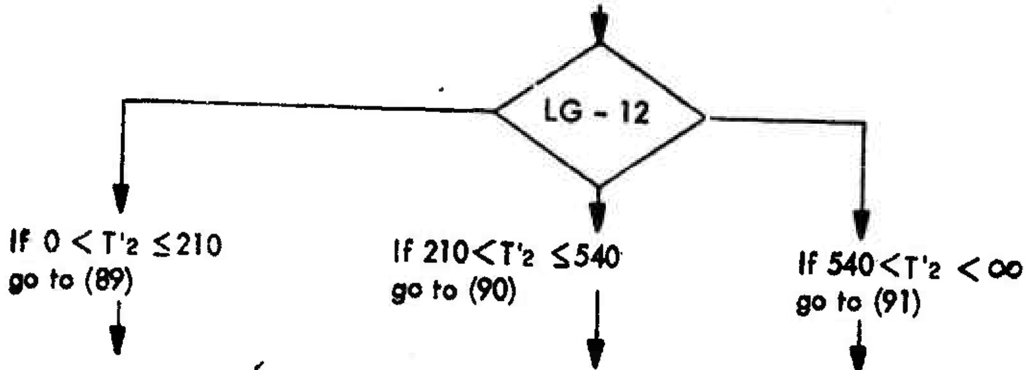
Then go to (92)

$$K_p = \frac{1}{\left[.1(T'_2 - T_{cm})\right]}\left\{-\left[\frac{(.1\,T'_2)^{2.708} - (.1\,T_{cm})^{2.708}}{2.708}\right] + 9.551\left[(.1\,T'_2)^2 - (.1\,T_{cm})^2\right]\right\} \tag{87}$$

Then go to (92)

$$K_p = 111.74 = \text{constant} \tag{88}$$

Then go to (92)



$$K_p = \frac{1}{(T'_2 - T_{cm})}\left\{\frac{2.765}{2}\left[(T'_2)^2 - (T_{cm})^2\right] - \left[\frac{(T'_2)^{2.16} - (T_{cm})^{2.16}}{2.16}\right]\right\} \tag{89}$$

Then go to (92)

$$K_p = 86.0 + \left\{6.25\left(\frac{\left[(T'_2 + T_{cm})/2\right] - 210}{330}\right)\right\} \tag{90}$$

Then go to (92)

$$Kp = 92.25 = \text{constant} \tag{91}$$

Then go to (92)

$$K_{4-5} = Kp \;\; .93061 \left[\frac{s - dh}{s - (dh/2)}\right] \tag{92)*}$$

$$U = \frac{1}{\dfrac{1}{h_{1-2}} + \dfrac{\ell_1}{K_{2-3}} + \dfrac{\ell_2}{K_{3-4}} + \dfrac{\ell_3}{K_{4-5}} + \dfrac{1}{h_{5-6}}} \tag{93)*}$$

$$ns = np + 1 \tag{94)*}$$

$$\ell e = \frac{ns \cdot ts}{12} \tag{95}$$

$$T\ell_1 = \frac{(T13 + T17)}{2} \tag{96}$$

$$T\ell_2 = \frac{(T12 + T18)}{2} \tag{97}$$

$$AK\ell = \frac{\left[(X^2/Fs) - (X'\,Y')\right] + \left[(C - 1)\,X'\,B'\right]}{144} \tag{98}$$

$$\bar{K}\ell = \frac{7.27 \times 10^{-3}}{(T\ell_2 - T\ell_1)} \left[\frac{(T\ell_2)^{1.585} - (T\ell_1)^{1.585}}{1.585}\right] \tag{99}$$

$$Q\ell = \frac{\bar{K}\ell \cdot Ak\ell}{\ell e} \tag{100)*}$$

LG-13

If $C_{h1} < C_{c2}$ go to (101)	If $C_{h1} > C_{c2}$ go to (104)	If $C_{h1} \equiv C_{c2} \pm 10^{-6}$ go to (107)

$\boxed{\text{If } C_{h1} < C_{c2}}$

$$\lambda = \frac{Q\,l}{3600\ C_{h1}} \qquad (101)^*$$

$$\epsilon = \epsilon_i\left(\frac{1}{1-\lambda}\right) \qquad (102)^*$$

TEST 7 - A

If (102) $\geq$ 1.0, stop & readout message . . . . . "REDUCE BORDER DIMENSIONS OR INCREASE t_s"

If (102) $<$ 1.0, continue.

$$N_{tu} = \frac{\log_e\left[\dfrac{1-\epsilon\,(C_{h1}/C_{c2})}{1-\epsilon}\right]}{1-(C_{h1}/C_{c2})} \qquad (103)^*$$

Then go to LG - 14

$\boxed{\text{If } C_{h1} > C_{c2}}$

$$\lambda = \frac{Q\,l}{3600\ C_{c2}} \qquad (104)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \tag{105}*$$

TEST 7-B

If (105) ≥ 1.0, stop & readout message . . . . . "REDUCE BORDER DIMENSIONS OR INCREASE ts"

If (105) < 1.0, continue.

$$N_{tu} = \frac{\log_e \left[\frac{1 - \epsilon \ (C_{c2}/C_{h1})}{1 - \epsilon} \right]}{1 - (C_{c2}/C_{h1})} \tag{106}*$$

Then go to LG - 14

$$\boxed{\text{If } C_{h1} \equiv C_{c2} \pm 10^{-6}}$$

$$\lambda = \frac{Q\ell}{3600 \ C_{h1}} \tag{107}*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \tag{108}*$$

TEST 7-C

If (108) ≥ 1.0, stop & readout message . . . . . "REDUCE BORDER DIMENSIONS OR INCREASE ts"

If (108) < 1.0, continue.

$$N_{tu} = \frac{\epsilon}{1 - \epsilon} \tag{109}*$$

Then go to LG -14

LG-14

If $Ch_1 < Cc_2$ go to (110)

If $Ch_1 > Cc_2$ go to (113)

If $Ch_1 \equiv Cc_2 \pm 10^{-6}$ go to (116)

$\boxed{\text{If } Ch_1 < Cc_2}$

$$Ax \text{ tot. hot side} = \frac{3600 \, Ntu \, Ch_1}{U} \tag{110*}$$

$$Axp = Ax_1 \cdot Af_1 \tag{111*}$$

$$n\beta \text{ calculated} = \frac{144 \; Ax \text{ tot. hot side}}{Axp} \tag{112}$$

Note . . . . . If a fraction results, go to next higher whole number.

TEST 8-A

(112) must = (4) $^{+1}_{-0}$

If (112) > (4), increase (4) and iterate from (4).

If (112) < (4), reduce (4) and iterate from (4).

Then go to (119)

$\boxed{\text{If } C_{h1} > C_{c2}}$

$$A_x \text{ tot. hot side} = \frac{3600 \, N_{tu} \, C_{c2}}{U} \qquad (113)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \qquad (114)^*$$

$$n_p \text{ calculated} = \frac{144 \, A_x \text{ tot. hot side}}{A_{xp}} \qquad (115)$$

Note . . . . . If a fraction results, go to next higher whole number.

TEST 8-B

(115) must = (4) $^{+1}_{-0}$

If (115) > (4), increase (4) and iterate from (4).

If (115) < (4), reduce (4) and iterate from (4).

Then go to (119)

$\boxed{\text{If } C_{h1} = C_{c2} \pm 10^{-6}}$

$$A_x \text{ tot. hot side} = \frac{3600 \, N_{tu} \, C_{h1}}{U} \qquad (116)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \qquad (117)^*$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{\text{Axp}} \tag{118}$$

Note . . . . . If a fraction results, go to next higher whole number.

TEST 8-C

(118) must = (4) $^{+1}_{-0}$

If (118) > (4), increase (4) and iterate from (4).

If (118) < (4), reduce (4) and iterate from (4).

Then go to (119)

$$\text{width X} = \underset{\text{after closure}}{\text{equation (13)}} = \text{inches} \qquad (119)^*$$

$$\text{height Y} = \frac{X}{Fs} = \text{inches} \qquad (120)^*$$

$$\text{core length L} = \left[(np \cdot tp) + (ns \cdot ts) \right] = \text{inches} \qquad (121)^*$$

$$\begin{aligned} \text{core weight} = .098 \text{ np tp} &\left\{ \left[(XY) - (X'Y') \right] + \left[X'B' (C-1) \right] + \left[Afi \ (Ra+1)\ (1-\sigma) \right] \right\} + \\ .078 \text{ ns ts} &\left\{ \left[(XY) - (X'Y') \right] + \left[X'B' (C-1) \right] \right\} = \text{lbs} \qquad (122)^* \end{aligned}$$

$$\text{header weight} = .196 \left[(XY) - Afi\ (Ra+1) + \frac{XY}{8} \right] = \text{lbs} \qquad (123)^*$$

$$\text{total weight} = (122) + (123) = \text{lbs} \qquad (124)^*$$

$$\eta f = \frac{1}{1 + \left[\dfrac{h_{1-2} \quad (Axp/Nh \cdot Yi') \quad (Yi')^2}{3\ np\ K_{2-3} \left\{ X'\ tp\ .93061 \left[\dfrac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \tag{125*}$$

TEST 9

If (125) < .40, read out message . . . . . "INCREASE (1P-40)."

If (125) > .60, readout message . . . . . "REDUCE (1P-40)."

Do not stop machine on TEST 9

$$Av = \frac{Ax\ tot.\ hot\ side}{\left(\dfrac{X \cdot Y \cdot L}{1728} \right)} \tag{126*}$$

$$\Delta H_{t1} = \bar{c}_p \quad T12 \quad \eta t \left[1 - (P17/P12)^{(\bar{\gamma} - 1)/\bar{\gamma}} \right] = \text{BTU/lb} \tag{127*}$$

$$\text{Turbine output} = 1054.54 \quad W_{t1} \cdot \Delta H_{t1} = \text{Watts} \tag{128*}$$

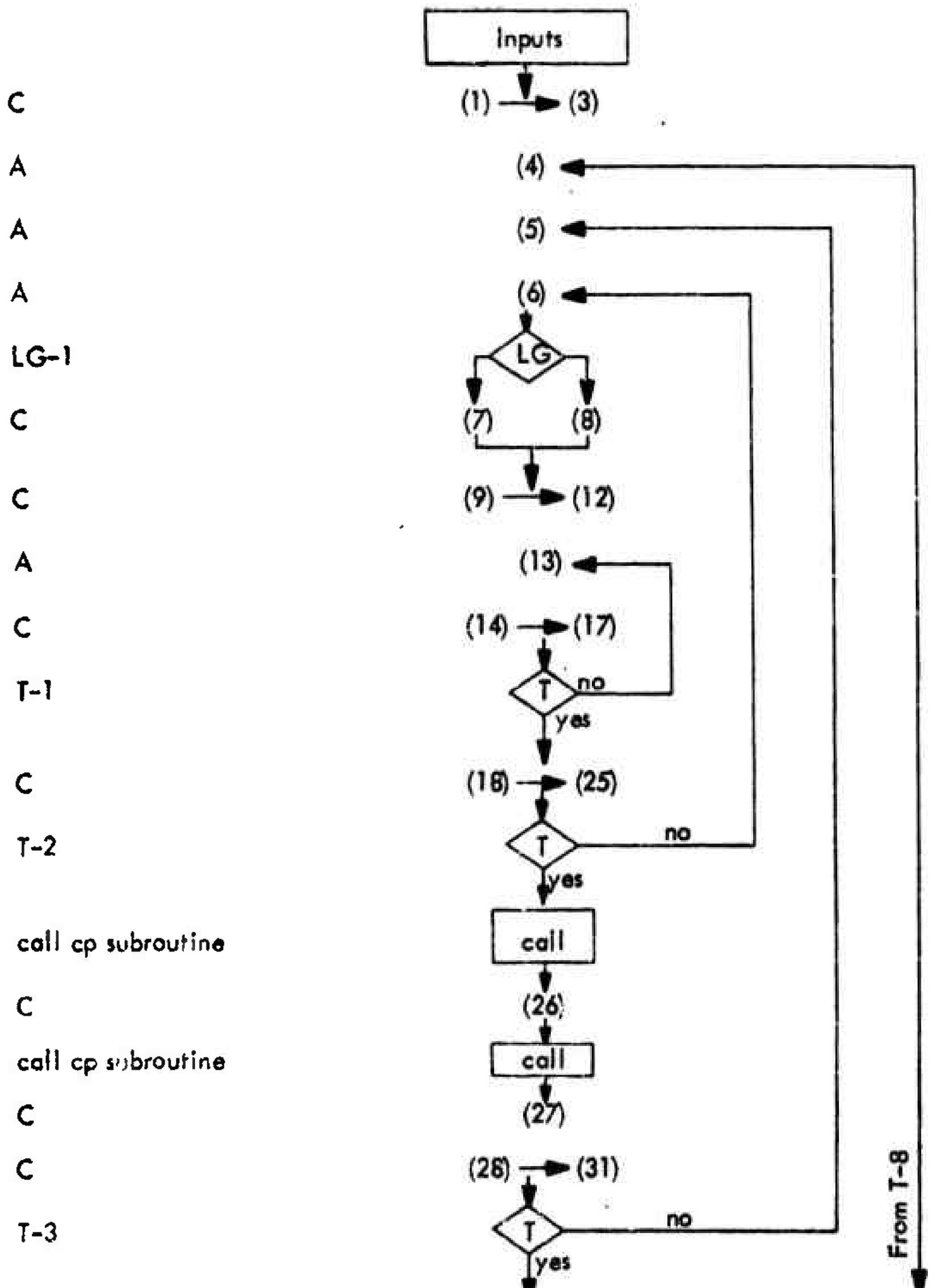
FINAL TEST

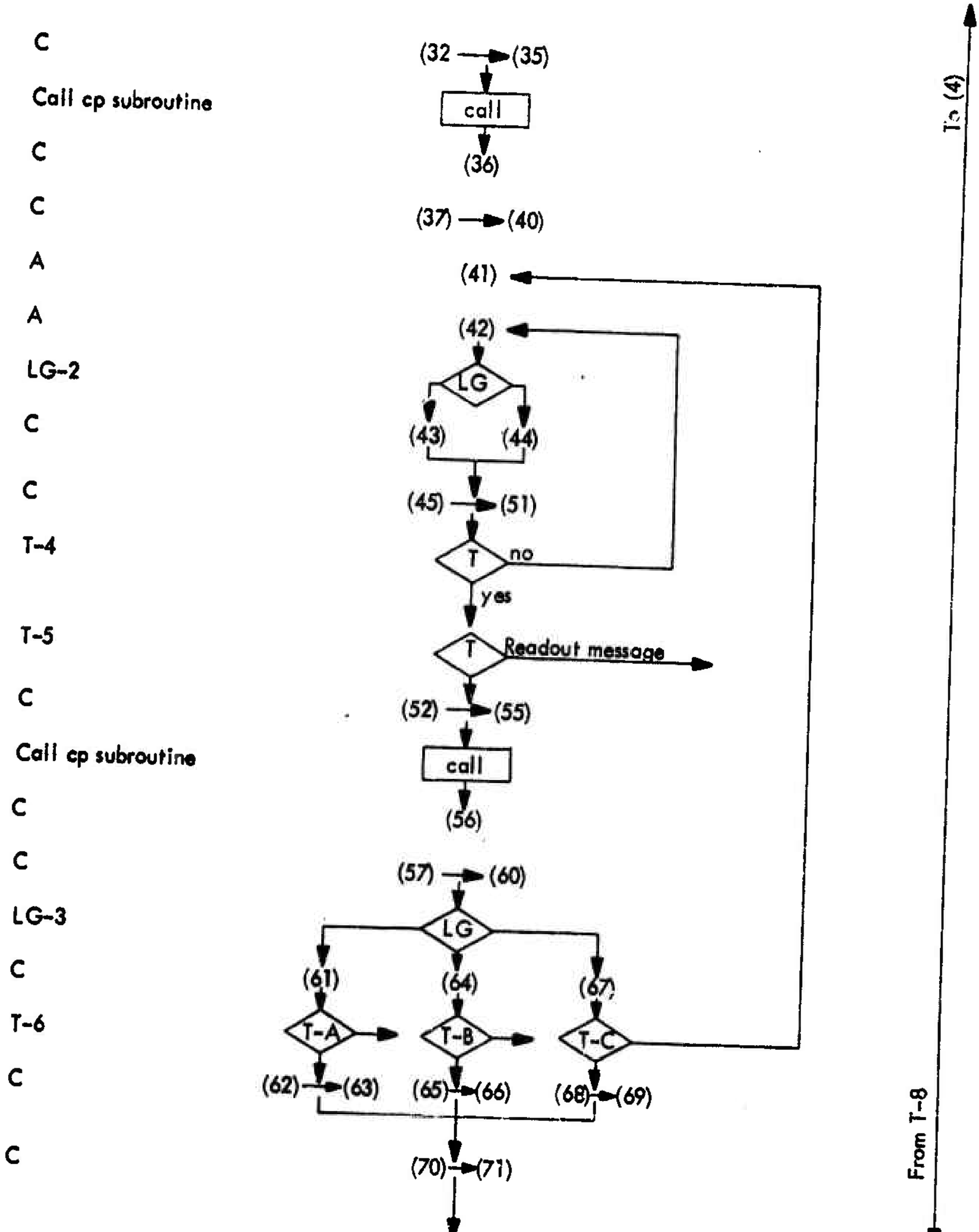
If (41) ≥ 540, stop machine.

If (41) < 540, call $HX(J)_{j=3}$ and continue.

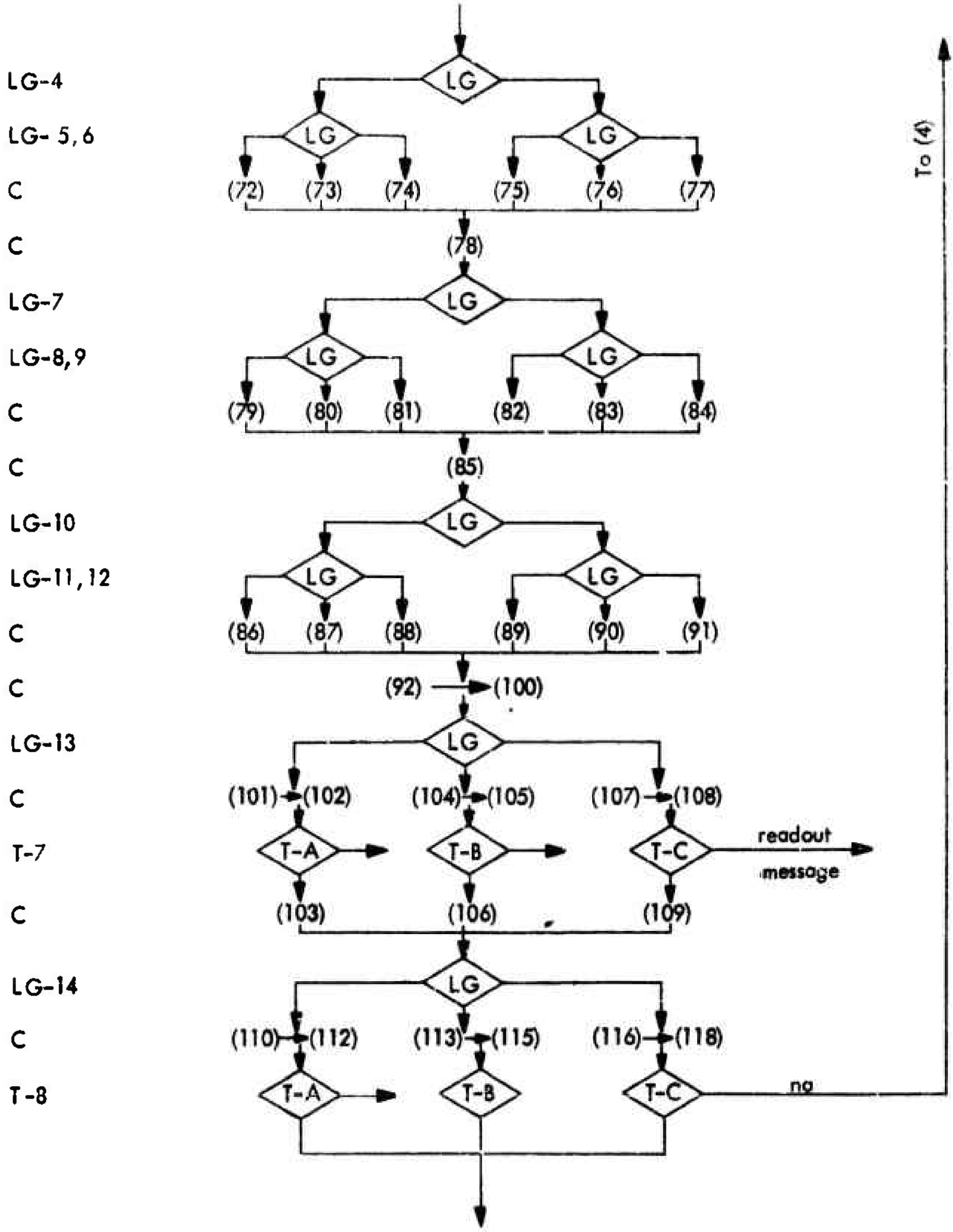
FLOW DIAGRAM FOR HX-2 AND TUBINE 1

A = assume
C = compute
LG = logic gate
T = test





C
Call cp subroutine
C
C
A
A
LG-2
C
C
T-4
T-5
C
Call cp subroutine
C
C
LG-3
C
T-6
C
C
(32 → (35)
call
(36)
(37) → (40)
(41)
(42)
LG
(43)
(44)
(45) → (51)
T
no
yes
T
Readout message
(52) → (55)
call
(56)
(57) → (60)
LG
(61)
(64)
(67)
T-A
T-B
T-C
(62) → (63)
(65) → (66)
(68) → (69)
(70) → (71)
To (4)
From T-8

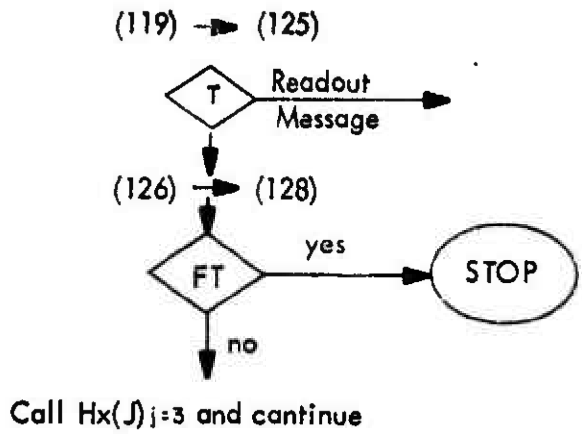

LG-4
LG- 5, 6
C
C
LG-7
LG-8, 9
C
C
LG-10
LG-11, 12
C
C
LG-13
C
T-7
C
LG-14
C
T-8
LG
(72) (73) (74) (75) (76) (77)
(78)
(79) (80) (81) (82) (83) (84)
(85)
(86) (87) (88) (89) (90) (91)
(92) (100)
(101) (102) (104) (105) (107) (108)
T-A
T-B
T-C
readout message
(103) (106) (109)
(110) (112) (113) (115) (116) (118)
no
To (4)

C

T-9

C

Final test



APPENDIX IV

HX-3 PROGRA ' . . . . . CALL HX(J) j=3.0:

Inputs:

Call numerical values from APPENDIX I, Section IV.
Also call last resut far T12, P12, T18 and P18 from output of HX-2.

Initial numerical assumptions:

Equa. No:	Initial Value:
(4)	200.0
(5)	T12 + 75.0
(6)	1.02 P12
(13)	2.0
(35)	T18 + 75
(36)	.98 P18

Notes:

Readout last result of all equations marked with a star "*".
Do not stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \frac{dh^2}{\sigma}} \qquad (1)*$$

$$n = \frac{4\sigma}{\pi\, dh^2} \qquad (2)*$$

$$Axl = (n \pi\ dh\ \ tp) + 2\,(1 - \sigma\ ) \qquad (3)*$$

$$np = \text{assume} \qquad (4)*$$

(Will be altered only by TEST 8)

$$T11 = \text{assume} \tag{5*}$$

(Will be altered only by TEST 6)

$$P11 = \text{assume} \tag{6*}$$

(Will be altered only by TEST 2)

LG-1

If $6 \leq T11 \leq 40$

$$\bar{\nu}_{11} = \left\{\left[\frac{2.765}{.03\left[\sqrt[3]{P11} \,/ (T11/40)\right]}\right]\left(\frac{T11}{P11}\right)\right\} \tag{7}$$

If $40 < T11 < \infty$

$$\bar{\nu}_{11} = 2.863092\left(\frac{T11}{P11}\right) \tag{8}$$

$$\mu_{11} = 2.37888 \times 10^{-7} \, (T11)^{.643} \tag{9}$$

$$V11 = \frac{144 \, NRei \;\; \bar{\nu}_{11} \;\; \mu_{11}}{dh} \tag{10*}$$

$$ahi = \frac{144 \;\; W2 \;\; \bar{\nu}_{11}}{V11} \tag{11*}$$

$$Af_i = \frac{ah_i}{\sigma} \tag{12*}$$

$$X = \text{assume} \tag{13*}$$

(Will be altered only be TEST 1)

$$X' = X - (2\ Bx) \tag{14*}$$

$$Y' = \frac{X}{Fs} - (2\ By) \tag{15*}$$

$$Y'_1 = \frac{Y' - \left[(C-1)\,B'\right] - Nh}{2\,(C-1)} \tag{16*}$$

$$Af_1 \text{ calculated} = Nh\,(X'\,Y'_1) \tag{17}$$

TEST 1

(17) must = (12) $\pm .001$

If (17) $>$ (12), reduce (13) and iterate from (13).

If (17) $<$ (12), increase (13) and iterate from (13).

$$Y'_2 = Y'_1 \frac{Ra}{2} \tag{18*}$$

$$Y'_3 = Y'_1 \cdot Ra \tag{19*}$$

$$l_1 = \frac{Y'_1}{24} \tag{20}$$

$$l_2 = \frac{B'}{12} \tag{21}$$

$$l_3 = \frac{Y'_3}{12 \cdot Ra} \tag{22}$$

$$\Delta P'_1 = \frac{370 \times 10^{-6}\; V_{11}^{\;2}}{\bar{\nu}_{11}} \sqrt{\frac{(l_p/dh)}{NRe_1}} \tag{23}$$

$$\Delta P_1 = np \cdot \Delta P'_1 \tag{24*}$$

$$P11 \text{ calculated} = P12 + \Delta P_1 \tag{25}$$

TEST 2

(25) must = (6) ± .001

If (25) > (6), increase (6) and iterate from (6).

If (25) < (6), reduce (6) and iterate from (6).

$$\mu m_I = \frac{8.55497 \times 10^{-4}}{(T11 - T12)} \left\{ \frac{(T11)^{1.643} - (T12)^{1.643}}{1.643} \right\} \tag{26}$$

$$Km_I = \frac{57.79 \times 10^{-3}}{[.00355\,(T11 - T12)]} \left\{ \frac{(.00355\,T11)^{1.642} - (.00355\,T12)^{1.642}}{1.642} \right\} \tag{27}$$

$$Thm = \frac{\left(\dfrac{Km_I}{57.79 \times 10^{-3}}\right)^{1/.642}}{.00355} \tag{28}$$

$$Phm = \frac{(P11 + P12)}{2} \tag{29}$$

Call cp subroutine and, with Thm and Phm . . . . . get

cphm = (30)

Ch_I = cphm · W2 (31)*

$$NPr_I = \frac{cphm \cdot \mu m_I}{Km_I}$$ (32)*

$$N_{Nu1} = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(fp/dh)}{N_{Re1} \cdot N_{Pr1}} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(fp/dh)}{N_{Re1} \cdot N_{Pr1}} \right]} \right)^{.8}} \right\} \tag{33*}$$

$$h_{1-2} = \frac{12\, N_{Nu1} \cdot K_{m1}}{dh} \tag{34*}$$

COLD SIDE:

$$T19 = \text{assume} \tag{35*}$$

(Will be altered only by TEST 5)

$$P19 = \text{assume} \tag{36*}$$

(Will be altered only by TEST 3)

If $6 \leq T19 \leq 40$ — LG-2 — If $40 < T19 < \infty$

$$\nu_{19} = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P19}/(T19/40)\right]}} \right] \left(\frac{T19}{P19} \right) \right\} \tag{37}$$

$$\nu_{19} = 2.863092 \left(\frac{T19}{P19} \right) \tag{38}$$

$$ah_2 = ah_1 \cdot Ra \tag{39*}$$

$$V19 = \frac{144\,W2 \quad \bar{\mathcal{V}}_{19}}{a h_2} \tag{40)*}$$

$$\mu_{19} = 2.37888 \times 10^{-7}\ (T19)^{.643} \tag{41}$$

$$NRe_2 = \frac{V19 \cdot dh}{12\,\bar{\mathcal{V}}_{19} \cdot \mu_{19}} \tag{42)*}$$

$$\Delta P'_2 = \frac{370 \times 10^{-6}\ V_{19}^2}{\bar{\mathcal{V}}_{19}} \sqrt{\frac{(tp/dh)}{NRe_2}} \tag{43}$$

$$\Delta P_2 = np \cdot \Delta P'_2 \tag{44)*}$$

$$P19 \text{ calculated} = P18 - \Delta P_2 \tag{45}$$

TEST 3

(45) must = (36) ±.001

If (45) > (36), increase (36) and iterate from (36)

If (45) < (36), reduce (36) and iterate from (36).

TEST 4

If (45) < 10, stop & readout message . . . . . "REDUCE NRe_1 OR INCREASE Ra"

If (45) ≥ 10, continue.

$$\mu m2 = \frac{8.55497 \times 10^{\text{[illegible]}}}{(T19 - T18)} \left\{ \frac{(T19)^{1.643} - (T18)^{1.643}}{1.643} \right\} \tag{46}$$

$$Km2 = \frac{57.79 \times 10^{-3}}{[.00355\,(T19 - T18)]} \left\{ \frac{(.00355\ T19)^{1.642} - (.00355\ T18)^{1.642}}{1.642} \right\} \tag{47}$$

$$Tcm = \frac{\left(\dfrac{Km2}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \tag{48}$$

$$Pcm = \frac{(P18 + P19)}{2} \tag{49}$$

Call cp subroutine and, with Tcm and Pcm . . . . get

$$cpcm = \tag{50}$$

$$Cc2 = cpcm \cdot W2 \tag{51)*}$$

$$NPr2 = \frac{cpcm \cdot \mu m2}{Km2} \tag{52)*}$$

$$NNu2 = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]^{.8}} \right)} \right\} \tag{53)*}$$

$$h_{5-6} = \frac{12\, N_{Nu2} \cdot K_{m2}}{d_h} \qquad (54)^*$$

LG-3

If $C_{h1} < C_{c2}$ go to (55)

If $C_{h1} > C_{c2}$ go to (61)

If $C_{h1} \cong C_{c2} \pm 10^{-6}$ go to (67)

$\boxed{\text{If } C_{h1} < C_{c2}}$

$$\nabla 1 = (T12 - T18)\, e^{N_{tu1}\left[1 - (C_{h1}/C_{c2})\right]} \qquad (55)$$

$$\Delta X = \frac{\nabla_1 - (T12 - T18)}{\left(\frac{C_{c2}}{C_{h1}}\right) - 1} \qquad (56)$$

$$\Delta Y = \left(\frac{C_{c2}}{C_{h1}}\right) \cdot \Delta X \qquad (57)$$

$$T19 \text{ calculated} = T18 + \Delta X \qquad (58)$$

TEST 5-A

(58) must = (35) ± .001

If (58) > (35), increase (35) and iterate from (35).

If (58) < (35), reduce (35) and iterate from (35).

$$T11 \text{ calculated} = T12 + \Delta Y \qquad (59)$$

TEST 6-A

(59) must = (5) ±.001

If (59) > (5), increase (5) and iterate from (5).

If (59) < (5), reduce (5) and iterate from (5).

$$\epsilon_i = \frac{1 - e^{-Ntui\left[1-(Ch_1/Cc_2)\right]}}{1-\left\{\left(\frac{Ch_1}{Cc_2}\right) e^{-Ntui\left[1-(Ch_1/Cc_2)\right]}\right\}} \quad (60)^*$$

Then go to (71)

$$\boxed{\text{If } Ch_1 > Cc_2}$$

$$\nabla 1 = (T12 - T18)\, e^{Ntui\left[1-(Cc_2/Ch_1)\right]} \quad (61)$$

$$\Delta X = \frac{\nabla_1 - (T12 - T18)}{\left(\frac{Ch_1}{Cc_2}\right) - 1} \quad (62)$$

$$\Delta Y = \left(\frac{Ch_1}{Cc_2}\right) \cdot \Delta X \quad (63)$$

$$T19 \text{ calculated} = T18 + \Delta X \quad (64)$$

TEST 5-B

(64) must = (35) ±.001

If (64) > (35), increase (35) and iterate from (35).

If (64) < (35), reduce (35) and iterate from (35).

$$T11 \text{ calculated} = T12 + \Delta Y \qquad (65)$$

TEST 6–B

(65) must = (5) ±.001

If (65) >(5), increase (5) and iterate from (5).

If (65)< (5), reduce (5) and iterate from (5).

$$\epsilon_i = \frac{1-e^{-Ntui\left[1-(Cc2/Ch_i)\right]}}{1-\left\{\left(\frac{Cc2}{Ch_i}\right)e^{-Ntui\left[1-(Cc2/Ch_i)\right]}\right\}} \qquad (66)^*$$

Then go to (71)

$$\boxed{\text{If } Ch_i \equiv Cc2 \pm 10^{-6}}$$

$$Z = \frac{(T12 - T18)}{1-\left(\frac{Ntui}{1+Ntui}\right)} \qquad (67)$$

$$T19 \text{ calculated} = (T18 + Z) - (T12 - T18) \qquad (68)$$

TEST 5–C

(68) must = (35) ±.001

If (68) >(35), increase (35) and iterate from (35).

If (68)< (35), reduce (35) and iterate from (35).

$$T11 \text{ calculated} = T18 + Z \qquad (69)$$

TEST 6-C

(69) must [illegible] (5) ± .001

If (69) > (5), increase (5) and iterate from (5).

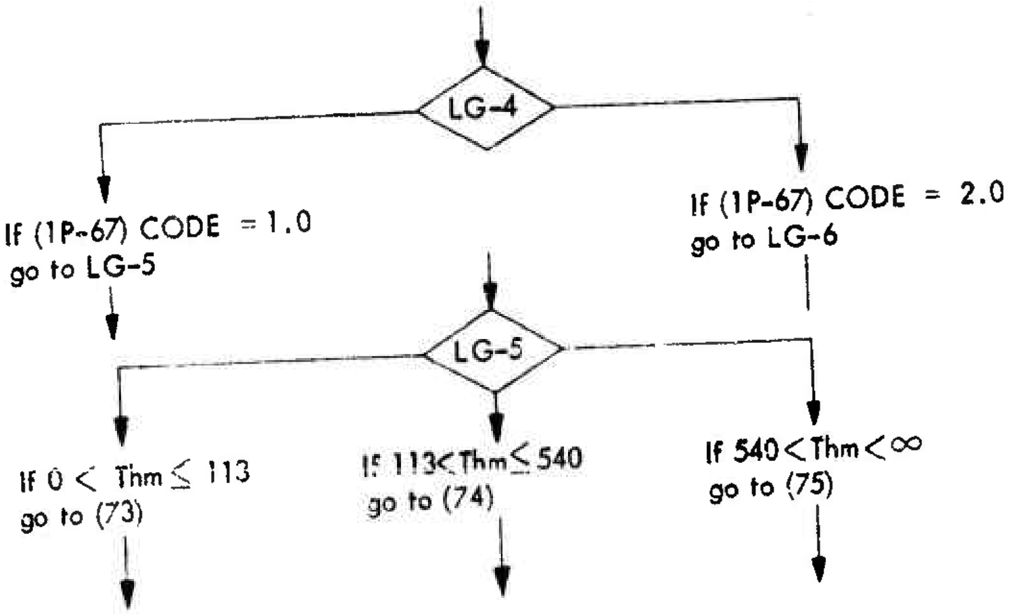
If (69) < (5), reduce (5) and iterate from (5).

$$\epsilon_i = \frac{Ntui}{1 + Ntui} \tag{70*}$$

Then to to (71)

$$T'_1 = Thm - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \tag{71}$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \tag{72}$$



$$Kp = \frac{1}{\left[.1\,(Thm - T'_1)\right]} \left\{ \frac{49}{2}\left[(.1\ Thm)^2 - (.1T'_1)^2\right] - \frac{1}{3.47}\left[(.1\ Thm)^{3.47} - (.1\ T'_1)^{3.47}\right] \right\} \tag{73}$$

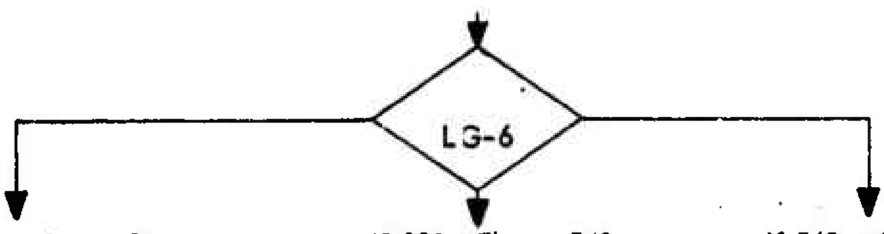
Then go to (79)

$$Kp = \frac{1}{\left[.1(Thm - T'_1)\right]} \left\{ -\left[\frac{(.1\ Thm)^{2.708} - (.1\ T'_1)^{2.708}}{2.708}\right] + 9.551\left[(.1\ Thm)^2 - (.1\ T'_1)^2\right] \right\} \tag{74}$$

Then go to (79)

$$Kp = 111.74 = \text{constant} \tag{75}$$

Then go to (79)



If $0 < Thm \leq 210$ go to (76)

If $210 < Thm \leq 540$ go to (77)

If $540 < Thm < \infty$ go to (78)

$$Kp = \frac{1}{(Thm - T'_1)} \left\{ \frac{2.765}{2}\left[(Thm)^2 - (T'_1)^2\right] - \left[\frac{(Thm)^{2.16} - (T'_1)^{2.16}}{2.16}\right] \right\} \tag{76}$$

Then go to (79)

$$Kp = 86.0 + \left\{ 6.25\left(\frac{\left[(Thm + T'_1)/2\right] - 210}{330}\right) \right\} \tag{77}$$

Then go to (79)

$$Kp = 92.25 = \text{constant} \tag{78}$$

Then go to (79)

$$_{2-3}K = Kp\ .93061 \left[\frac{s - dh}{s - (dh/2)}\right] \tag{79*}$$

LG-7

If (1P-67) CODE = 1.0
go to LG-8

If (1P-67) CODE = 2.0
go to LG-9

LG-8

If $0 < T'_1 \leq 113$
go to (80)

If $113 < T'_1 \leq 540$
go to (81)

If $540 < T'_1 \leq \infty$
go to (82)

$$Kp = \frac{1}{\left[.1(T'_1 - T'_2)\right]} \left\{ \frac{49}{2}\left[(.1\,T'_1)^2 - (.1\,T'_2)^2\right] - \frac{1}{3.47}\left[(.1\,T'_1)^{3.47} - (.1\,T'_2)^{3.47}\right] \right\} \tag{80}$$

Then go to (86)

$$Kp = \frac{1}{\left[.1\,(T'_1 - T'_2)\right]} \left\{ - \left[\frac{(.1\,T'_1)^{2.708} - (.1\,T'_2)^{2.708}}{2.708}\right] + 9.551\left[(.1T'_1)^2 - (.1\,T'_2)^2\right] \right\} \tag{81}$$

Then go to (86)

$$K_p = 111.74 = \text{constant} \tag{82}$$

Then go to (86)

LG-9

If $0 < T'_1 \leq 210$ go to (83)

If $210 < T'_1 \leq 540$ go to (84)

If $540 < T'_1 < \infty$ go to (85)

$$K_p = \frac{1}{(T'_1 - T'_2)} \left\{ \frac{2.765}{2} \left[(T'_1)^2 - (T'_2)^2 \right] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16} \right] \right\} \tag{83}$$

Then go to (86)

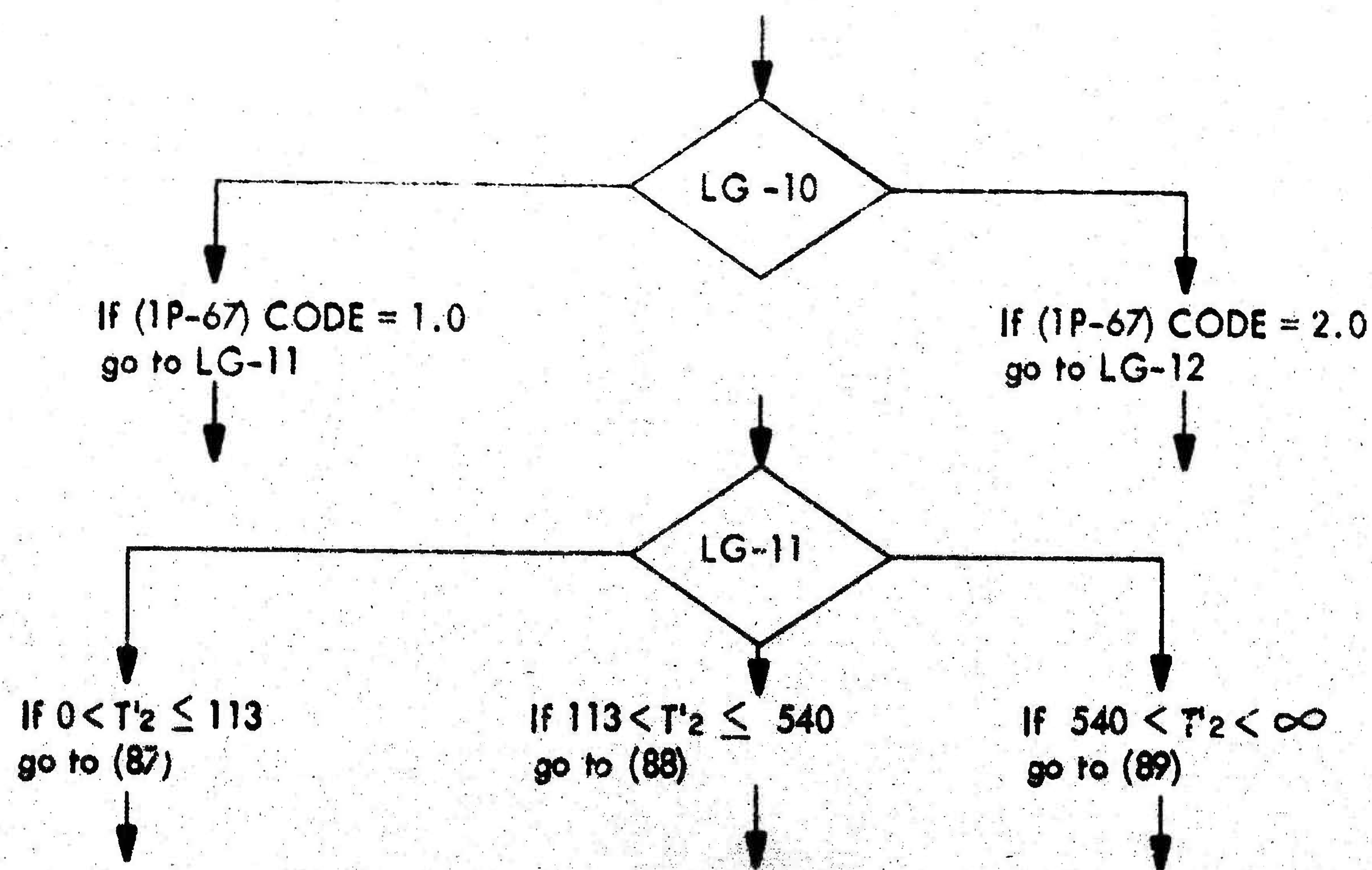
$$K_p = 86.0 + \left\{ 6.25 \left(\frac{\left[(T'_1 + T'_2)/2 \right] - 210}{330} \right) \right\} \tag{84}$$

Then go to (86)

$$K_p = 92.25 = \text{constant} \tag{85}$$

Then go to (86)

$$K_{3-4} = K_p \qquad (86)^{*}$$



$$K_p = \frac{1}{\left[.1\,(T'_2 - T_{cm})\right]}\left\{\frac{49}{2}\left[(.1\,T'_2)^2 - (.1\,T_{cm})^2\right] - \frac{1}{3.47}\left[(.1\,T'_2)^{3.47} - (.1\,T_{cm})^{3.47}\right]\right\} \qquad (87)$$

Then go to (93)

$$K_p = \frac{1}{\left[.1\,(T'_2 - T_{cm})\right]}\left\{-\left[\frac{(.1T'_2)^{2.708} - (.1\,T_{cm})^{2.708}}{2.708}\right] + 9.551\left[(.1\,T'_2)^2 - (.1\,T_{cm})^2\right]\right\} \qquad (88)$$

Then go to (93)

$$Kp = 111.74 = \text{constant} \tag{89}$$

Then go to (93)

LG-12

If $0 < T'_2 \leq 210$ go to (90)

If $210 < T'_2 \leq 540$ go to (91)

If $540 < T'_2 < \infty$ go to (92)

$$Kp = \frac{1}{(T'_2 - T_{cm})} \left\{ \frac{2.765}{2} \left[(T'_2)^2 - (T_{cm})^2 \right] - \left[\frac{(T'_2)^{2.16} - (T_{cm})^{2.16}}{2.16} \right] \right\} \tag{90}$$

Then go to (93)

$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(T'_2 + T_{cm})/2\right] - 210}{330} \right) \right\} \tag{91}$$

Then go to (93)

$$Kp = 92.25 = \text{constant} \tag{92}$$

Then go to (93)

$$k_{4-5} = K_p \ .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \qquad (93)^*$$

$$U = \frac{1}{\left(\dfrac{1}{h_{1-2}} + \dfrac{\ell_1}{K_{2-3}} + \dfrac{\ell_2}{K_{3-4}} + \dfrac{\ell_3}{K_{4-5}} + \dfrac{1}{h_{5-6}} \right)} \qquad (94)^*$$

$$ns = np + 1 \qquad (95)^*$$

$$\ell e = \frac{ns \cdot ts}{12} \qquad (96)$$

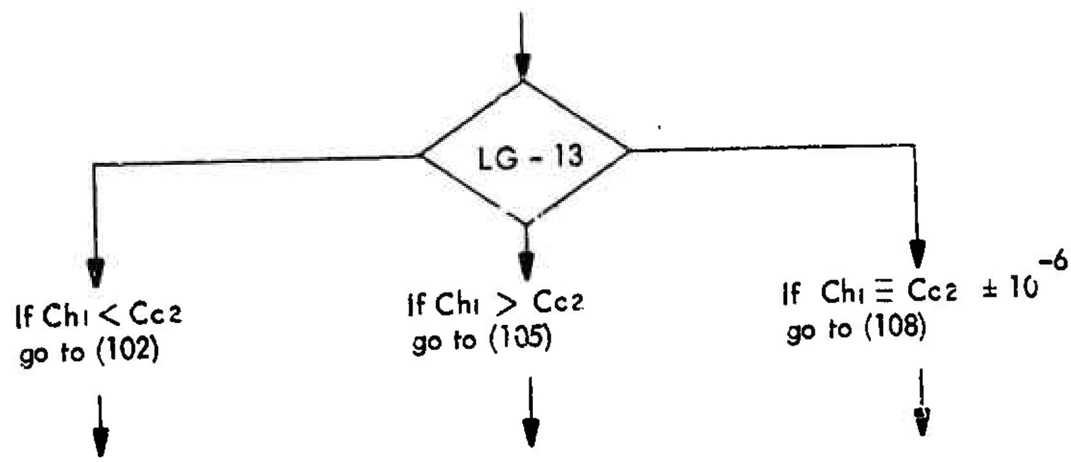
$$T\ell_1 = \frac{(T12 + T18)}{2} \qquad (97)$$

$$T\ell_2 = \frac{(T11 + T19)}{2} \qquad (98)$$

$$Ak\ell = \frac{\left[\left(X^2/Fs \right) - (X' \ Y') \right] + \left[(C-1) \ \ X'B' \right]}{144} \qquad (99)$$

$$\bar{K}\ell = \frac{7.27 \times 10^{-3}}{(T\ell_2 - T\ell_1)} \left[\frac{(T\ell_2)^{1.585} - (T\ell_1)^{1.585}}{1.585} \right] \qquad (100)$$

$$Q_l = \frac{\bar{K}_l \cdot A_{kl}}{l_e} \qquad (101)^*$$



$\boxed{\text{If } Chi \text{ [illegible] } Cc2}$

$$\lambda = \frac{Ql}{3600\ Chi} \qquad (102)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (103)^*$$

TEST 7 - A

If (103) $\geq$ 1.0, stop & readout message . . . . . "REDUCE Ntui"
" " $<$ " , continue.

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left(Chi/Cc2 \right)}{1 - \epsilon} \right]}{1 - \left(Chi/Cc2 \right)} \qquad (104)^*$$

Then go to LG - 14

$\boxed{\text{If } Chi > Cc2}$

$$\lambda = \frac{Ql}{3600\ Cc2} \qquad (105)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (106)^*$$

TEST 7 - B

If (106) $\geq$ 1.0, stop & readout message . . . . . "REDUCE Ntui"
" " $<$ " , continue.

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left(Cc2/Ch1 \right)}{1 - \epsilon} \right]}{1 - \left(Cc2/Ch1 \right)} \qquad (107)^*$$

Then go to LG - 14

$$\boxed{\text{If } Ch1 \equiv Cc2 \pm 10^{-6}}$$

$$\lambda = \frac{Q\ell}{3600\ Ch1} \qquad (108)^*$$

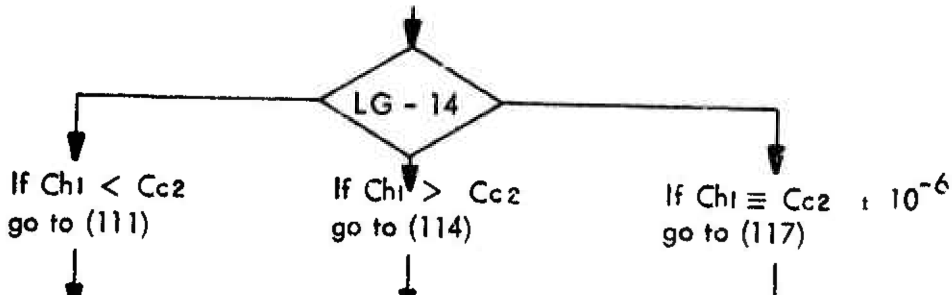
$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (109)^*$$

TEST 7 - C

If (109) $\geq$ 1.0, stop & readout message . . . . . "REDUCE Ntui"
" " < " , continue.

$$Ntu = \frac{\epsilon}{1 - \epsilon} \qquad (110)^*$$

Then go to LG - 14



$$\boxed{\text{If } C_{h1} < C_{c2}}$$

$$\text{Ax tot. hot side} = \frac{3600\ Ntu \cdot C_{h1}}{U} \qquad (111)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (112)^*$$

$$\text{np calculated} = \frac{144\ \text{Ax tot. hot side}}{Axp} \qquad (113)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8-A
(113) must = (4) $\pm {1 \atop 0}$
If (113) > (4), increases (4) and iterate from (4).
" " < ", reduce " " " ".

Then go to (120)

$$\boxed{\text{If } C_{h1} > C_{c2}}$$

$$\text{Ax tot. hot side} = \frac{3600\ Ntu \cdot C_{c2}}{U} \qquad (114)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (115)^*$$

$$\text{np calculated} = \frac{144\ \text{Ax tot. hot side}}{Axp} \qquad (116)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8 - B

$$(116) \text{ must } = (4) \begin{smallmatrix} +1 \\ -0 \end{smallmatrix}$$

If (116) > (4), increase (4) and iterate from (4).
" " < ", reduce " " " ".

Then go to (120)

$$\boxed{\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}}$$

$$\text{Ax tot. hot side} = \frac{3600 \text{ Ntu} \cdot Ch_1}{U} \qquad (117)$$

$$Axp = Ax_1 \cdot Af_1 \qquad (118)$$

$$\text{np calculated} = \frac{114 \text{ Ax tot. hot side}}{Axp} \qquad (119)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8 - C

$$(119) \text{ must } = (4) \begin{smallmatrix} +1 \\ -0 \end{smallmatrix}$$

If (119) > (4), increase (4) and iterate from (4).
" " < ", reduce " " " ".

Then go to (120)

$$\text{width } X = \text{equation (15) after closure} = \text{inches} \tag{120*}$$

$$\text{height } Y' = \frac{Y}{Fs} = \text{inches} \tag{121*}$$

$$\text{core length } L = \left[(np \cdot tp) + (ns \cdot ts)\right] = \text{inches} \tag{122*}$$

$$\text{core weight} = .098\ np\ tp \left\{ \left[(XY) - (X'\,Y')\right] + \left[X'\,B'\,(C-1)\right] + \left[Af_1\,(Ra+1)(1-\sigma)\right] \right\} + .078\ ns\ ts \left\{ \left[(XY) - (X'\,Y')\right] + \left[X'\,B'\,(c-1)\right] \right\} = \text{lbs} \tag{123*}$$

$$\text{header weight} = .196 \left[(XY) - Af_1\ (Ra+1) + \frac{XY}{8} \right] = \text{lbs} \tag{124*}$$

$$\text{total weight} = (123) + (124) = \text{lbs} \tag{125*}$$

$$\eta f = \frac{1}{1 + \left[\dfrac{h_{1-2} \left(\dfrac{Axp}{Nh \cdot Y'_1} \right) (Y'_1)^2}{3\ np\ K_{2-3} \left\{ X'\ tp\ .93061 \left[\dfrac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \tag{126*}$$

TEST 9

If (126) < .40, readaut message . . . . . "INCREASE (IP-60)."
" " > .60, " " . . . . . "REDUCE (IP-60)."

Da nat stop mochine on TEST 9.

$$Av = \frac{\text{Ax tot. hat side}}{\left(\dfrac{X \cdot Y \cdot L}{1728} \right)} = ft^2/ft^3 \tag{127*}$$

FINAL TEST

If $(35) \geq 540$, stop machine.

" " < " , call $\underset{j=4}{HX(J)}$ and continue.

The FLOW DIAGRAM for HX-3 is exactly similar to that of HX-1.

APPENDIX V

HX-4 AND TURBINE 2 PROGRAM . . . . . CALL HX(J) $_{j=4.0}$:

Inputs:

Call numerical valves from APPENDIX I, Section V. Also c[illegible] last result for T11, P11, T19 and P19 from output of HX-3.

Initial numerical assumptions:

Equa. No.	Initial Value:
(4)	30.0
(5)	T11 + 10
(6)	1.02 P11
(13)	2.0
(41)	T19 + 10
(42)	.98 P19

Notes:

Readout last result of all equations marked with a star "*".
D[illegible] [illegible]ot stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \; \frac{dh^2}{\sigma}} \qquad (1)^*$$

$$n = \frac{4 \; \sigma}{\pi \; dh^2} \qquad (2)^*$$

$$Axi = (n \, \pi \, dh \; tp) + 2(1 - \sigma) \qquad (3)^*$$

$$np = \text{assume} \qquad (4)^*$$

(Will be altered only by TEST 8)

$$T10 = \text{assume} \qquad (5)^*$$

(Will be altered only by TEST 3)

$$P10 = \text{assume} \qquad (6)^*$$

(Will be altered only by TEST 2)

LG-1

If $6 \leq T10 \leq 40$

$$\vartheta_{10} = \left\{ \left[\frac{2.765}{.03\left[\sqrt[3]{P10/(T10/40)}\right]} \right] \left(\frac{T10}{P10} \right) \right\} \qquad (7)$$

If $40 < T10 < \infty$

$$\vartheta_{10} = 2.863092 \left(\frac{T10}{P10} \right) \qquad (8)$$

$$\mu_{10} = 2.37888 \times 10^{-7} \, (T10)^{.643} \qquad (9)$$

$$V_{10} = \frac{12\ NRe_{1}\ \bar{\nu}_{10}\ \mu_{10}}{dh} \tag{10}$$ *

$$ah_{1} = \frac{144\ W_{2}\ \bar{\nu}_{10}}{V_{10}} \tag{11}$$ *

$$Af_{1} = \frac{ah_{1}}{\sigma} \tag{12}$$ *

$$X = \text{assume} \tag{13}$$ *

(Will be altered only by TEST 1)

$$X' = X - (2\ Bx) \tag{14}$$ *

$$Y' = \frac{X}{Fs} - (2\ By) \tag{15}$$ *

$$Y_1 = \frac{Y' - \left[(C-1)\ B'\right] - Nh}{2\ (C-1)} \tag{16}$$ *

$$Af_{1}\ \text{calculated} = Nh\ (X'\ Y_1) \tag{17}$$

TEST 1

(17) must = (12) ± .001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " ".

$$Y_2 = Y_1\ \frac{Ra}{2} \tag{18}$$ *

$$Y_3 = Y_1 \cdot Ra \tag{19}$$ *

$$\ell_1 = \frac{Y'_1}{24} \qquad (20)$$

$$\ell_2 = \frac{B'}{12} \qquad (21)$$

$$\ell_3 = \frac{Y'_3}{12 \cdot Ra} \qquad (22)$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} \; V^2_{10}}{\bar{\nu}_{10}} \sqrt{\frac{(tp/dh)}{N \cdot Re_1}} \qquad (23)$$

$$\Delta P_1 = np \cdot \Delta P'_1 \qquad (24)^*$$

$$P10 \text{ calculated} = P11 + \Delta P_1 \qquad (25)$$

TEST 2

(25) must = (6) ± .001

If (25) > (6) increase (6) and iterate from (6).

" " < ", reduce " " " " ".

$\boxed{\text{Call cp subroutine and, with T10 and P10 .... get}}$

$cp10 = \leftarrow$ (26)

$\boxed{\text{Call cp subroutine and, with T19 and P19 .... get}}$

$cp19 = \leftarrow$ (27)

$$\overline{cp} = \frac{(cp10 + cp19)}{2} \tag{28}$$

$$\bar{\gamma} = \frac{1}{1 - \left(\frac{.496447487}{\overline{cp}}\right)} \tag{29}$$

$$\frac{T19}{T10} = 1 - \eta t \left[1 - \left({P19}/{P10} \right)^{(\bar{\gamma} - 1)/\bar{\gamma}} \right] \tag{30}$$

$$\text{T10 calculated} = \frac{T19}{(T19/T10)} \tag{31}$$

TEST 3

(31) must = (5) ± .001

If (31) > (5), increases (5) and iterate from (5).

" " < " reduce " " " " ".

$$\mu mi = \frac{8.55497 \times 10^{-4}}{(T10 - T11)} \left\{ \frac{(T10)^{1.643} - (T11)^{1.643}}{1.643} \right\} \tag{32}$$

$$Kmi = \frac{57.79 \times 10^{-3}}{[.00355\,(T10 - T11)]} \left\{ \frac{(.00355\ T10)^{1.642} - (.00355\ T11)^{1.642}}{1.642} \right\} \tag{33}$$

$$\mathrm{Thm} = \frac{\left(\dfrac{\mathrm{Km_1}}{57.79 \times 10^{-3}}\right)^{1/.642}}{.00355} \tag{34}$$

$$\mathrm{Phm} = \frac{(\mathrm{P10} + \mathrm{P11})}{2} \tag{35}$$

Call cp subroutine and, with Thm and Phm . . . . get

$$\mathrm{cphm} = \tag{36}$$

$$\mathrm{Ch_1} = \mathrm{cphm} \cdot \mathrm{W_2} \tag{37)*$$

$$\mathrm{NPr_1} = \frac{\mathrm{cphm} \cdot \mu \mathrm{m_1}}{\mathrm{Km_1}} \tag{38)*$$

$$\mathrm{NNu_1} = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{\mathrm{NRe_1} \cdot \mathrm{NPr_1}}\right]}\right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{\mathrm{NRe_1} \cdot \mathrm{NPr_1}}\right]^{.8}}\right)} \right\} \tag{39)*$$

$$h_{1-2} = \frac{12\ \mathrm{NNu_1} \cdot \mathrm{Km_1}}{dh} \tag{40)*$$

COLD SIDE:

$$T20 = \text{assume}$$

(Will be altered only by TEST 6) (41)*

$$P20 = \text{assume}$$

(Will be altered only by TEST 4) (42)*

LG-2

If $6 \leq T20 \leq 40$

$$\bar{\nu}20 = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P20}\,/\,(T20/40)\right]}} \right] \left(\frac{T20}{P20}\right) \right\} \quad (43)$$

If $40 < T20 < \infty$

$$\bar{\nu}20 = 2.863092 \left(\frac{T20}{P20}\right) \quad (44)$$

$$\mu 20 = 2.37888 \times 10^{-7} \; (T20)^{.643} \quad (45)$$

$$ah2 = ah1 \cdot Ra \quad (46)^*$$

$$V20 = \frac{144 \;\; W3 \;\; \bar{\nu}20}{ah2} \quad (47)^*$$

$$NRe2 = \frac{V20 \cdot dh}{12 \;\; \bar{\nu}20 \cdot \mu 20} \quad (48)^*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} \, V^2 20}{\bar{\mathcal{N}}\, 20} \sqrt{\frac{(tp/dh)}{NRe_2}} \qquad (49)$$

$$\Delta P_2 = np \cdot \Delta P'_2 \qquad (50)^*$$

$$P20 \text{ calculated} = P19 - \Delta P_2 \qquad (51)$$

TEST 4

(51) must = (42) ± .001

If (51) > (42), increase (42) and iterate from (42).

" " < " , reduce " " " " " .

TEST 5

If (51) < 10, stop and readout message .... "INCREASE Ra"

" " ≥ ", continue.

$$\mu\, m_2 = \frac{8.55497 \times 10^{-4}}{(T20 - T19)} \cdot \left\{ \frac{(T20)^{1.643} - (T19)^{1.643}}{1.643} \right\} \qquad (52)$$

$$Km2 = \frac{57.79 \times 10^{-3}}{[.00355\,(T20 - T19)]} \left\{ \frac{(.00355T20)^{1.642} - (.00355T19)^{1.642}}{1.642} \right\} \qquad (53)$$

$$Tcm = \frac{\left(\frac{Km_1}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \qquad (54)$$

$$Pcm = \frac{(P19 + P20)}{2} \qquad (55)$$

Call cp subroutine and, with Tcm and Pcm ....get (56)

cpcm =

$$Cc2 = cpcm \cdot W3 \qquad (57)^*$$

$$NPr2 = \frac{cpcm \cdot \mu m2}{Km2} \qquad (58)^*$$

$$NNu2 = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)^{.8}} \right\} \qquad (59)^*$$

$$h_{5-6} = \frac{12\ NNu2 \cdot Km2}{dh} \qquad (60)^*$$

LG-3

If Ch1 < Cc2 go to (61)

If Ch1 > Cc2 go to (64)

If Ch1 ≡ Cc2 ± 10^{-6} go to (67)

$$\boxed{\text{If } C_{h1} < C_{c2}}$$

$$T20 \text{ calculated} = T19 + \left[\frac{(T10 - T11)}{(C_{c2} / C_{h1})}\right] \tag{61}$$

TEST 6 - A

(61) must = (41) ± .001

If (61) > (41), increase (41) and iterate from (41).

" " < ", reduce " " " " ".

$$N_{tui} = \frac{\log_e \left[\frac{(T10 - T20)}{(T11 - T19)}\right]}{1 - \left(C_{h1}/C_{c2}\right)} \tag{62*}$$

$$\epsilon_1 = \frac{1 - e^{-N_{tui}\left[1 - \left(C_{h1}/C_{c2}\right)\right]}}{1 - \left\{\left(\frac{C_{h1}}{C_{c2}}\right) e^{-N_{tui}\left[1 - \left(C_{h1}/C_{c2}\right)\right]}\right\}} \tag{63*}$$

Then go to (70)

$\boxed{\text{If } C_{h1} > C_{c2}}$

$$T20 \text{ calculated} = T19 + \left[\frac{(T10 - T11)}{\left({C_{h1}}/{C_{c2}} \right)} \right] \tag{64}$$

TEST 6 - B

(64) must = (41) ± .001

If (64) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " ".

$$N_{tui} = \frac{\log_e \left[\frac{(T10 - T20)}{(T11 - T19)} \right]}{1 - \left({C_{c2}}/{C_{h1}} \right)} \tag{65)*$$

$$\epsilon_i = \frac{1 - e^{-N_{tui} \left[1 - \left({C_{c2}}/{C_{h1}} \right) \right]}}{1 - \left\{ \left(\frac{C_{c2}}{C_{h1}} \right) e^{-N_{tui} \left[1 - \left({C_{c2}}/{C_{h1}} \right) \right]} \right\}} \tag{66)*$$

Then go to (70)

$$\boxed{\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}}$$

$$T20 \text{ calculated} = T10 - (T11 - T19) \tag{67}$$

TEST 6 - C

(67) must = (41) ± .001

If (67) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " ".

$$Ntui = \frac{\left[\frac{(T10 - T11)}{(T10 - T19)}\right]}{1 - \left[\frac{(T10 - T11)}{(T10 - T19)}\right]} \tag{68*}$$

$$\epsilon i = \frac{Ntui}{1 + Ntui} \tag{69*}$$

Then go to (70)

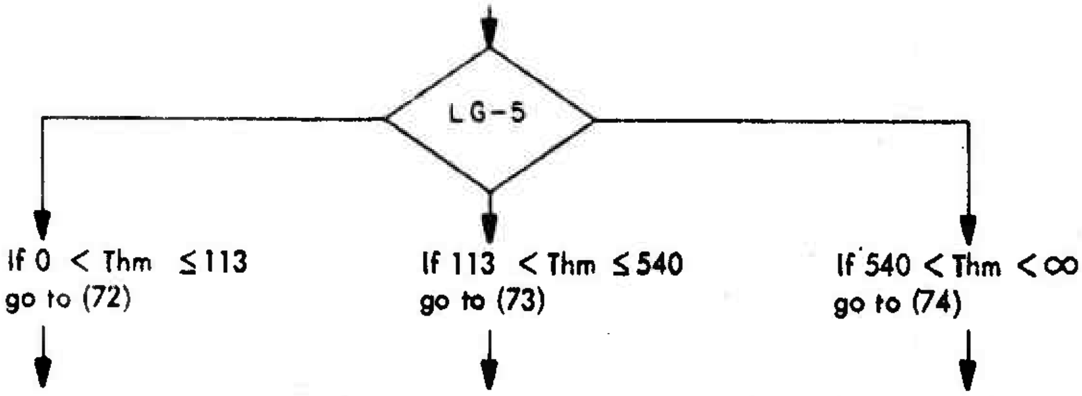
$$T'_1 = Thm - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3}\right)(Thm - Tcm)\right] \tag{70}$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3}\right)(Thm - Tcm)\right] \tag{71}$$

LG - 4

If (1P-86) CODE = 1.0
go to LG - 5

If (1P-86) CODE = 2.0
go to LG - 6



$$K_p = \frac{1}{[.1\,(Thm - T'_1)]}\left\{\frac{49}{2}\left[(.1\ Thm)^2 - (.1\ T'_1)^2\right] - \frac{1}{3.47}\left[(.1\ Thm)^{3.47} - (.1\ T'_1)^{3.47}\right]\right\} \tag{72}$$

Then go to (78)

$$K_p = \frac{1}{[.1\,(Thm - T'_1)]}\left\{-\left[\frac{(.1\ Thm)^{2.708} - (.1\,T'_1)^{2.708}}{2.708}\right] + 9.551\left[(.1\ Thm)^2 - (.1\ T'_1)^2\right]\right\} \tag{73}$$

Then go to (78)

$$K_p = 111.74 = \text{constant} \tag{74}$$

Then go to (78)

LG-6

If $0 < Thm \leq 210$
go to (75)

If $210 < Thm \leq 540$
go to (76)

If $540 < Thm < \infty$
go to (77)

$$Kp = \frac{1}{(Thm - T'_1)} \left\{ \frac{2.765}{2} \left[(Thm)^2 - (T'_1)^2 \right] - \left[\frac{(Thm)^{2.16} - (T'_1)^{2.16}}{2.16} \right] \right\} \qquad (75)$$

Then go to (78)

$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(Thm + T'_1)/2 \right] - 210}{330} \right) \right\} \qquad (76)$$

Then go to (78)

$$Kp = 92.25 = \text{constant} \qquad (77)$$

Then go to (78)

$${}_{2-3}K = Kp \quad .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \qquad (78)\ *$$

LG - 7

If (1P - 86) CODE = 1.0
go to LG - 8

If (1P - 86) CODE = 2.0
go to LG - 9

LG-8

If $0 < T'_1 \leq 113$ go to (79)

If $113 < T'_1 \leq 540$ go to (80)

If $540 < T'_1 < \infty$ go to (81)

$$KP = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ \frac{49}{2} \left[(.1T'_1)^2 - (.1T'_2)^2 \right] - \frac{1}{3.47} \left[(.1T'_1)^{3.47} - (.1T'_2)^{3.47} \right] \right\} \tag{79}$$

Then go to (85)

$$Kp = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ - \left[\frac{(.1T'_1)^{2.708} - (.1T'_2)^{2.708}}{2.708} \right] + 9.551 \left[(.1T'_1)^2 - (.1T'_2)^2 \right] \right\} \tag{80}$$

Then go to (85)

$$Kp = 111.74 = \text{constant} \tag{81}$$

Then go to (85)

LG - 9

If $0 < T'_1 \leq 210$ go to (82)

If $210 < T'_1 \leq 540$ go to (83)

If $540 < T'_1 < \infty$ go to (84)

$$Kp = \frac{1}{(T'_1 - T'_2)} \left\{ \frac{2.765}{2} \left[(T'_1)^2 - (T'_2)^2 \right] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16} \right] \right\} \tag{82}$$

Then go to (85)

$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(T'_1 + T'_2)/2\right] - 210}{330} \right) \right\} \tag{83}$$

Then go to (85)

$$Kp = 92.25 = \text{constant} \tag{84}$$

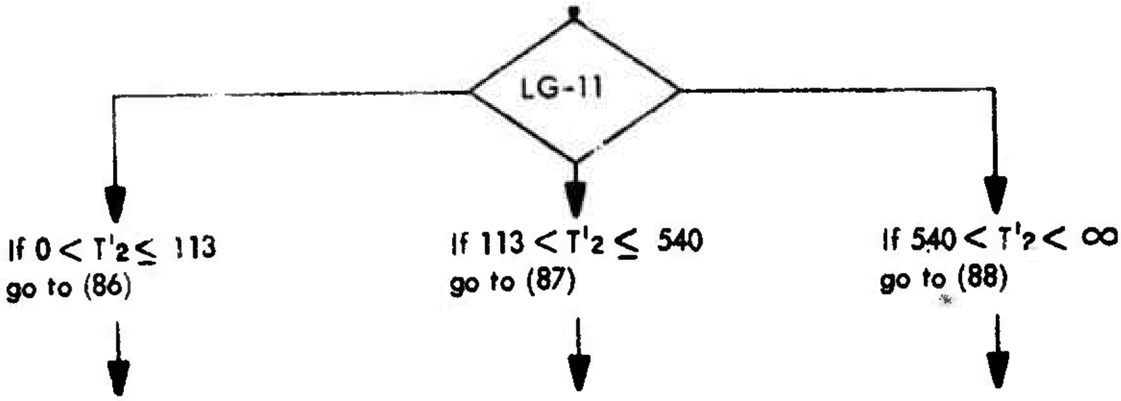
Then go to (85)

$$K_{3-4} = Kp \tag{85}^*$$

LG - 10

If (1P-86) CODE = 1.0 go to LG - 11

If (1P-86) CODE = 2.0 go to LG - 12



$$Kp = \frac{1}{[.1\,(T'_2 - T_{cm})]} \left\{ \frac{49}{2} \left[(.1T'_2)^2 - (.1T_{cm})^2 \right] - \frac{1}{3.47} \left[(.1T'_2)^{3.47} - (.1T_{cm})^{3.47} \right] \right\} \qquad (86)$$

Then go to (92)

$$Kp = \frac{1}{[.1\,(T'_2 - T_{cm})]} \left\{ - \left[\frac{(.1T'_2)^{2.708} - (.1T_{cm})^{2.708}}{2.708} \right] + 9.551 \left[(.1T'_2)^2 - (.1T_{cm})^2 \right] \right\} \qquad (87)$$

Then go to (92)

$$Kp = 111.74 = \text{constant} \qquad (88)$$

Then go to (92)

LG-12

If $0 < T'_2 \leq 210$ go to (89)

If $210 < T'_2 \leq 540$ go to (90)

If $540 < T'_2 < \infty$ go to (91)

$$Kp = \frac{1}{(T'_2 - Tcm)} \left\{ \frac{2.765}{2} \left[(T'_2)^2 - (Tcm)^2 \right] - \left[\frac{(T'_2)^{2.16} - (Tcm)^{2.16}}{2.16} \right] \right\} \tag{89}$$

Then go to (92)

$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(T'_2 + Tcm)/2 \right] - 210}{330} \right) \right\} \tag{90}$$

Then go to (92)

$$Kp = 92.25 = \text{constant} \tag{91}$$

Then go to (92)

$$K_{4-5} = Kp \ .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \tag{92*}$$

$$U = \frac{1}{\frac{1}{h_{1-2}} + \frac{\ell_1}{K_{2-3}} + \frac{\ell_2}{K_{3-4}} + \frac{\ell_3}{K_{4-5}} + \frac{1}{h_{5-6}}} \tag{93*}$$

$$ns = np + 1 \qquad (94)^*$$

$$\ell e = \frac{ns \cdot ts}{12} \qquad (95)$$

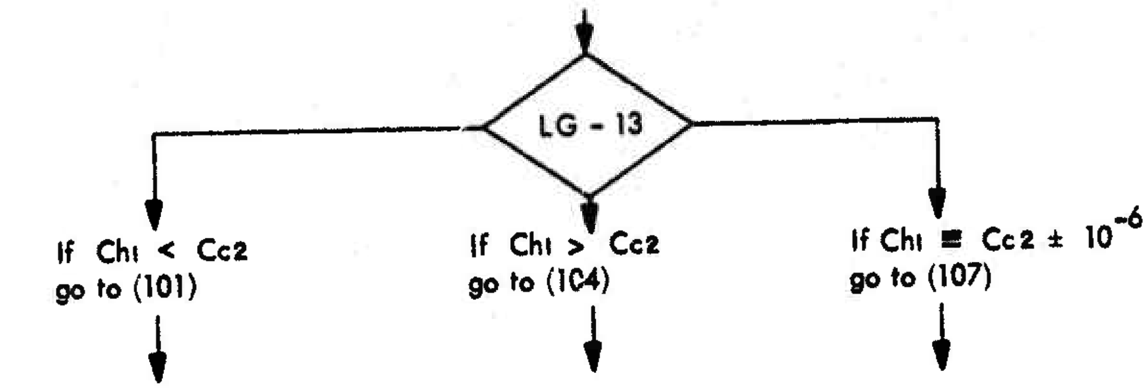
$$T\ell_1 = \frac{(T11 + T19)}{2} \qquad (96)$$

$$T\ell_2 = \frac{(T10 + T20)}{2} \qquad (97)$$

$$Ak\ell = \frac{\left[(X^2/Fs) - (X'Y')\right] + \left[(C - 1)\ X'B'\right]}{144} \qquad (98)$$

$$\overline{K\ell} = \frac{7.27 \times 10^{-3}}{(T\ell_2 - T\ell_1)} \left[\frac{(T\ell_2)^{1.585} - (T\ell_1)^{1.585}}{1.585}\right] \qquad (99)$$

$$Q\ell = \frac{\overline{K\ell} \cdot Ak\ell}{\ell e} \qquad (100)^*$$



$$\boxed{\text{If } C_{h1} < C_{c2}}$$

$$\lambda = \frac{Q\,l}{3600\ C_{h1}} \qquad (101)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (102)^*$$

TEST 7 - A

If (102) $\geq$ 1.0, stop and readout message ...... "REDUCE BORDER DIMS. OR INCREASE ts"

" " < " , continue.

$$N_{tu} = \frac{\log_e \left[\dfrac{1 - \epsilon \left(C_{h1}/C_{c2} \right)}{1 - \epsilon} \right]}{1 - \left(C_{h1}/C_{c2} \right)} \qquad (103)^*$$

Then go to LG - 14

$$\boxed{\text{If } C_{h1} > C_{c2}}$$

$$\lambda = \frac{Q\,l}{3600\ C_{c2}} \qquad (104)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (105)^*$$

TEST 7 - B

If (105) $\geq$ 1.0, stop and readout message .... "REDUCE BORDER DIMS. OR INCREASE ts"

" " < " , continue

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left({Cc2}/{Ch1} \right)}{1 - \epsilon} \right]}{1 - \left({Cc2}/{Ch1} \right)} \tag{106*}$$

Then go to LG - 14

$$\boxed{\text{If } Ch1 \equiv Cc2 \pm 10^{-6}}$$

$$\lambda = \frac{Q2}{3600 \; Ch1} \tag{107*}$$

$$\epsilon = \epsilon 1 \left(\frac{1}{1 - \lambda} \right) \tag{108*}$$

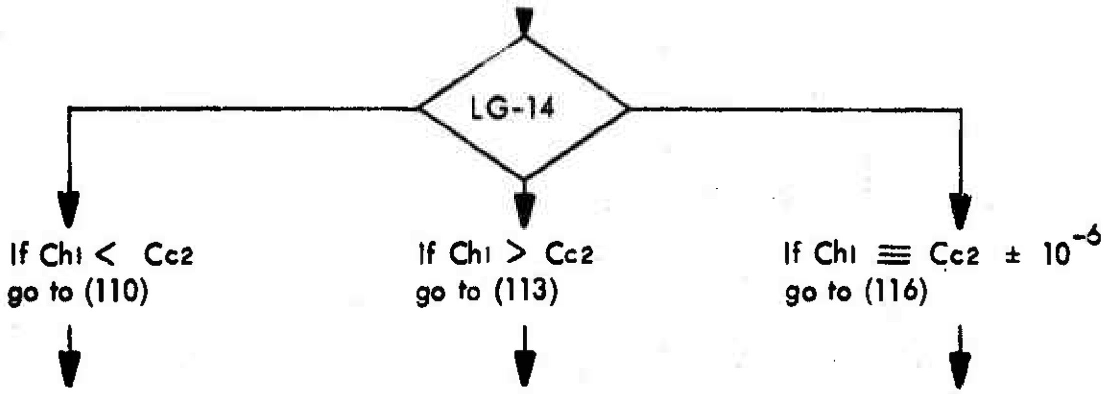
TEST 7 - C

If (108) $\geq$ 1.0, stop and readout message .... "REDUCE BORDER DIMS. OR INCREASE ts"

" " < " , continue

$$Ntu = \frac{\epsilon}{1 - \epsilon} \tag{109*}$$

Then go to LG - 14



$\boxed{\text{If } C_{h1} < C_{c2}}$

$$A_x \text{ tot. hot side} = \frac{3600 \; N_{tu} \cdot C_{h1}}{U} \qquad (110)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \qquad (111)^*$$

$$n_p \text{ calculated} = \frac{144 \; A_x \text{ tot. hot side}}{A_{xp}} \qquad (112)$$

Note .... If a fraction results, go to next higher whole number

TEST 8 - A

(112) must = (4) $^{+1}_{-0}$

If (112) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " ".

Then go to (119)

$\boxed{\text{If } C_{h1} > C_{c2}}$

$$A_x \text{ tot. hot side} = \frac{3600 \; N_{tu} \cdot C_{c2}}{U} \qquad (113)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (114)^*$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{Axp} \qquad (115)$$

Note . . . . If a fraction results, go to next higher whole number.

TEST 8 - B

(115) must = (4) $^{+1}_{-0}$

If (115) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " " ".

Then go to (119)

$$\boxed{\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}}$$

$$\text{Ax tot. hot side} = \frac{3600 \text{ Ntu } Ch_1}{U} \qquad (116)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (117)^*$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{Axp} \qquad (118)$$

Note . . . . If a fraction results, go to next higher whole number.

TEST 8 - C

(118) must = (4) $^{+1}_{-0}$

If (118) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " " ".

Then go to (119)

$$\text{width } X = \text{equation (13) after closure} = \text{inches} \tag{119*}$$

$$\text{height } Y = \frac{X}{Fs} = \text{inches} \tag{120*}$$

$$\text{core length } L = \left[(np \cdot tp) + (ns \cdot ts)\right] = \text{inches} \tag{121*}$$

$$\text{core weight} = .098\, np\, tp \left\{\left[(XY) - (X'Y')\right] + \left[X'B'\,(C-1)\right] + \left[Af_1\,(Ra+1)\,(1-\sigma)\right]\right\} + .078\, ns\, ts \left\{\left[(XY) - (X'Y')\right] + \left[X'B'\,(C-1)\right]\right\} = \text{lbs} \tag{122*}$$

$$\text{header weight} = .196 \left[(XY) - Af_1\,(Ra+1) + \frac{XY}{8}\right] = \text{lbs} \tag{123*}$$

$$\text{total weight} = (122) + (123) = \text{lbs} \tag{124*}$$

$$\eta f = \frac{1}{1 + \left[\dfrac{I^{h}_{1-2} \left({}^{Axp}/_{Nh} \cdot Y'_1 \right) \quad (Y'_1)^2}{3\, np\; {}_2K_3 \left\{ X'\, t_F \quad 3061 \left[\dfrac{s - dh}{s - (dh/2)}\right] \right\}}\right]} \tag{125*}$$

TEST 9

If (125) < .40, readout message ….. "INCREASE (IP-76)."

If " > " " " ….. "REDUCE " ."

Do <u>not</u> stop machine on TEST 9.

$$Av = \frac{\text{Ax tot. hot side}}{\left(\frac{X \cdot Y \cdot L}{1728}\right)} = ft^2/ft^3 \qquad (126)^*$$

$$\Delta Ht_2 = cp \; T10 \; \eta t \left[1 - \left(P19/P10\right)^{(\bar{\gamma} - 1)/\bar{\gamma}}\right] = BTU/lb$$

(127)*

$$\text{Turbine output} = 1054.54 \; Wt_2 \cdot \Delta Ht_2 = \text{Watts} \qquad (128)^*$$

FINAL TEST

If (41) $\geq$ 540, stop machine

" " $<$ " , call HX $(J)_{j=5.0}$ and continue.

The FLOW DIAGRAM for HX - 4 is exactly similar to that of HX - 2.

APPENDIX VI

HX - 5 PROGRAM .... CALL $HX(J)_{j=5,0}$:

<u>Inputs:</u>

Call numerical values from APPENDIX I, Section VI.
Also call last result for T10, P10, T20 and P20 from output of HX-4

<u>Initial numerical assumptions:</u>

Equa. No	Initial Value
(4)	250.0
(5)	T10 + 100
(6)	1.02 P10
(13)	2.0
(35)	T20 + 100
(36)	.98 P20

<u>Notes:</u>

Readout last result of all equations marked with a star " * "

Do <u>not</u> stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \, \frac{dh^2}{\sigma}} \qquad (1)^*$$

$$n = \frac{4\,\sigma}{\pi \, dh^2} \qquad (2)^*$$

$$Axi = (n \, \pi \, dh \, tp) + 2\,(1 - \sigma) \qquad (3)^*$$

$$np = \text{assume} \qquad (4)^*$$

(Will be altered only by TEST 8)

$$T9 = \text{assume} \qquad (5)^*$$

(Will be altered only by TEST 6)

$$P9 = \text{assume} \qquad (6)^*$$

(Will be altered only by TEST 2)

LG - 1

If $6 \leq T9 \leq 40$

$$\bar{N}_9 = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P9}\,/\,(T9/40)\right]}} \right] \left(\frac{T9}{P9} \right) \right\} \qquad (7)$$

If $40 < T9 < \infty$

$$\bar{N}_9 = 2.863092 \left(\frac{T9}{P9} \right) \qquad (8)$$

$$\mu_9 = 2.37888 \times 10^{-7} \, (T9)^{.643} \tag{9}$$

$$V9 = \frac{12 \;\; NRe_I \;\; \bar{\nu}_9 \;\; \mu_9}{dh} \tag{10)*$$

$$ah_I = \frac{144 \;\; W3 \;\; \bar{\nu}_9}{V9} \tag{11)*$$

$$Af_I = \frac{ahi}{\sigma} \tag{12)*$$

$$X = \text{assume} \tag{13)*$$

(Will be altered only by Test 1)

$$X' = X - (2 \;\; Bx) \tag{14)*$$

$$Y' = \frac{X}{Fs} - (2 \;\; By) \tag{15)*$$

$$Y'_I = \frac{Y' - \left[(C - 1) \;\; B' \right] - Nh}{2 \;\; (C - 1)} \tag{16)*$$

$$Af_I \text{ calculated} = Nh \;\; (X'Y'_I) \tag{17}$$

TEST 1

(17) must = (12) ± .001

If (17) > (12), reduce (13) and iterate from (13).

" " < ", increase " " " " ".

$$Y'_2 = Y'_1 \; \frac{Ra}{2} \tag{18)*(}$$

$$Y'_3 = Y'_1 \cdot Rc \tag{19)*(}$$

$$\ell_1 = \frac{Y'_1}{24} \tag{20}$$

$$\ell_2 = \frac{B'}{12} \tag{21}$$

$$\ell_3 = \frac{Y'_3}{12 \cdot Rc} \tag{22}$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} \; V_9^2}{\bar{\rho}_9} \sqrt{\frac{(tp/dh)}{Nre_1}} \tag{23}$$

$$\Delta P_1 = np \cdot \Delta P'_1 \tag{24)*(}$$

$$P9 \text{ calculated} = P10 + \Delta P_1 \tag{25}$$

TEST 2

(25) must = (6) ± .001

If (25) > (6), increase (6) and iterate from (6).

" " < " , reduce " " " " ".

$$\mu_{m1} = \frac{8.55497 \times 10^{-4}}{(T9 - T10)} \left\{ \frac{(T9)^{1.643} - (T10)^{1.643}}{1.643} \right\} \tag{26}$$

$$Km_1 = \frac{57.79 \times 10^{-3}}{\left[.00355 \ (T9 - T10)\right]} \left\{ \frac{(.00355\ T9)^{1.642} - (.00355\ T10)^{1.642}}{1.642} \right\} \tag{27}$$

$$Thm = \frac{\left(\dfrac{Km1}{57.79 \times 10^{-3}}\right)^{1/.642}}{.00355} \tag{28}$$

$$Phm = \frac{(P9 + P10)}{2} \tag{29}$$

$$\boxed{\text{Call cp subroutine and, with Thm and Phm .... get}}$$

$$cphm = \tag{30}$$

$$Ch_1 = cphm \cdot W_3 \qquad (31)^*$$

$$NPr_1 = \frac{cphm \cdot \mu_{m1}}{Km_1} \qquad (32)^*$$

$$NNu_1 = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{NRe_1 \cdot NPr_1} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{NRe_1 \cdot NPr_1} \right]^{.8}} \right)} \right\} \qquad (33)^*$$

$$h_{1-2} = \frac{12 \; NNu_1 \cdot Km_1}{dh} \qquad (34)^*$$

COLD SIDE:

$T21$ = assume

(Will be altered only by TEST 5) (35)*

$P21$ = assume

(Will be altered only by TEST 3) (36)*

LG-2

If $6 \leq T21 \leq 40$

If $40 < T21 < \infty$

$$\bar{\nu}\,21 = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P21}/(T21/40)\right]}} \right] \left(\frac{T21}{P21} \right) \right\} \qquad (37)$$

$$\bar{\nu}_{21} = 2.863092 \left(\frac{T21}{P21} \right) \qquad (38)$$

$$ah_2 = ah_1 \cdot Ra \qquad (39)^*$$

$$V_{21} = \frac{144\ W_3\ \overline{\nu}_{21}}{ah_2} \qquad (40)^*$$

$$\mu_{21} = 2.37888 \times 10^{-7}\ (T21)^{.643} \qquad (41)$$

$$NRe_2 = \frac{V_{21}\ dh}{12\ \overline{\nu}_{21} \cdot \mu_{21}} \qquad (42)^*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6}\ V^2_{21}}{\overline{\nu}_{21}} \sqrt{\frac{(tp/dh)}{NRe_2}} \qquad (43)$$

$$\Delta P_2 = np \cdot \Delta P'_2 \qquad (44)^*$$

$$P_{21} \text{ calculated} = P_{20} - \Delta P_2 \qquad (45)$$

TEST 3

(45) must = (36) ± .001

If (45) > (36), increase (36) and iterate from (36).

" " < " , reduce " " " " " .

TEST 4

If (45) < 10, stop and readout message .... "REDUCE NRe_1 OR INCREASE Ra"

" " ≥ " , continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T_{21} - T_{20})} \left\{ \frac{(T_{21})^{1.643} - (T_{20})^{1.643}}{1.643} \right\} \qquad (46)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{[.00355\,(T_{21} - T_{20})]} \left\{ \frac{(.00355\,T_{21})^{1.642} - (.00355\,T_{20})^{1.642}}{1.642} \right\} \qquad (47)$$

$$T_{cm} = \frac{\left(\dfrac{K_{m2}}{57.79 \times 10^{-3}}\right)^{1/.642}}{.00355} \qquad (48)$$

$$P_{cm} = \frac{(P_{20} + P_{21})}{2} \qquad (49)$$

$$\boxed{\begin{array}{l}\text{Call cp subroutine and, with}\\ T_{cm} \text{ and } P_{cm} \text{..........get}\end{array}}$$

$$cpcm = \qquad (50)$$

$$C_{c2} = cpcm \cdot W_3 \qquad (51)^*$$

$$N_{Pr2} = \frac{cpcm \cdot \mu_{m2}}{K_{m2}} \qquad (52)^*$$

$$N_{Nu2} = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{N_{Re2} \cdot N_{Pr2}}\right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{N_{Re2} \cdot N_{Pr2}}\right]^{.8}} \right)} \right\} \tag{53}$$

(53)*

$$h_{5-6} = \frac{12 \; N_{Nu2} \cdot K_{m2}}{dh} \tag{54}$$

(54)*

LG-3

If $C_{h1} < C_{c2}$ go to (55)

If $C_{h1} > C_{c2}$ go to (61)

If $C_{h1} \equiv C_{c2} \pm 10^{-6}$ go to (67)

$\boxed{\text{If } C_{h1} < C_{c2}}$

$$\nabla_1 = (T_{10} - T_{20}) \; e^{N_{tu1} \left[1 - \left(C_{h1} / C_{c2} \right) \right]} \tag{55}$$

$$\Delta X = \frac{\nabla_1 - (T10 - T20)}{\left(\dfrac{C_{c2}}{C_{h1}}\right) - 1} \tag{56}$$

$$\Delta Y = \left(\frac{C_{c2}}{C_{h1}}\right) \cdot \Delta X \tag{57}$$

$$T21 \text{ calculated } = T20 + \Delta X \tag{58}$$

TEST 5 - A

(58) must = (35) ± .001

If (58) > (35), increase (35) and iterate from (35).

" " < ", reduce " " " " " .

$$T9 \text{ calculated } = T10 + \Delta Y \tag{59}$$

TEST 6 - A

(59) must = (5) ± .001

If (59) > (5), increase (5) and iterate from (5)

" " < ", reduce " " " " ".

$$\epsilon i = \frac{1 - e^{-Ntui\left[1 - (Chi / Cc2)\right]}}{1 - \left\{\left|\frac{Chi}{Cc2}\right| e^{-Ntui\left[1 - (Chi / Cc2)\right]}\right\}} \tag{60*}$$

Then go to (71)

$$\boxed{\text{If } Chi > Cc2}$$

$$\nabla 1 = (T10 - T20)\ e^{Ntui\left[1 - (Cc2 / Chi)\right]} \tag{61}$$

$$\Delta X = \frac{\nabla 1 - (T10 - T20)}{\left|\frac{Chi}{Cc2}\right| - 1} \tag{62}$$

$$\Delta Y = \left|\frac{Chi}{Cc2}\right| \cdot \Delta X \tag{63}$$

$$T21 \text{ calculated} = T20 + \Delta X \tag{64}$$

TEST 5 - B

(64) must = (35) ± .001

If (64) > (35), increase (35) and iterate from (35).

" " < ", reduce " " " " "

$$T9 \text{ calculated} = T10 + \Delta Y \tag{65}$$

TEST 6 - B

(65) must = (5) ± .001

If (65) > (5), increase (5) and iterate from (5).

" " < ", reduce " " " " "

$$\epsilon i = \frac{1 - e^{-Ntui\left[1 - (Cc2/Chi)\right]}}{1 - \left\{\left(\frac{Cc2}{Chi}\right) e^{-Ntui\left[1 - \left(Cc2/Chi\right)\right]}\right\}} \tag{66}^{*}$$

Then go to (71)

$$\boxed{\text{If } Chi \equiv Cc2 \pm 10^{-6}}$$

$$Z = \frac{(T10 - T20)}{1 - \left(\frac{Ntui}{1 + Ntui}\right)} \tag{67}$$

$$T21 \text{ calculated } = (T20 + Z) - (T10 - T20) \tag{68}$$

TEST 5 - C

(68) must = (35) ± .001

If (68) > (35), increase (35) and iterate from (35)

" " < " , reduce " " " " ".

$$T9 \text{ calculated } = T20 + Z \tag{69}$$

TEST 6 - C

(69) must = (5) ± .001

If (69) > (5) , increase (5) and iterate from (5)

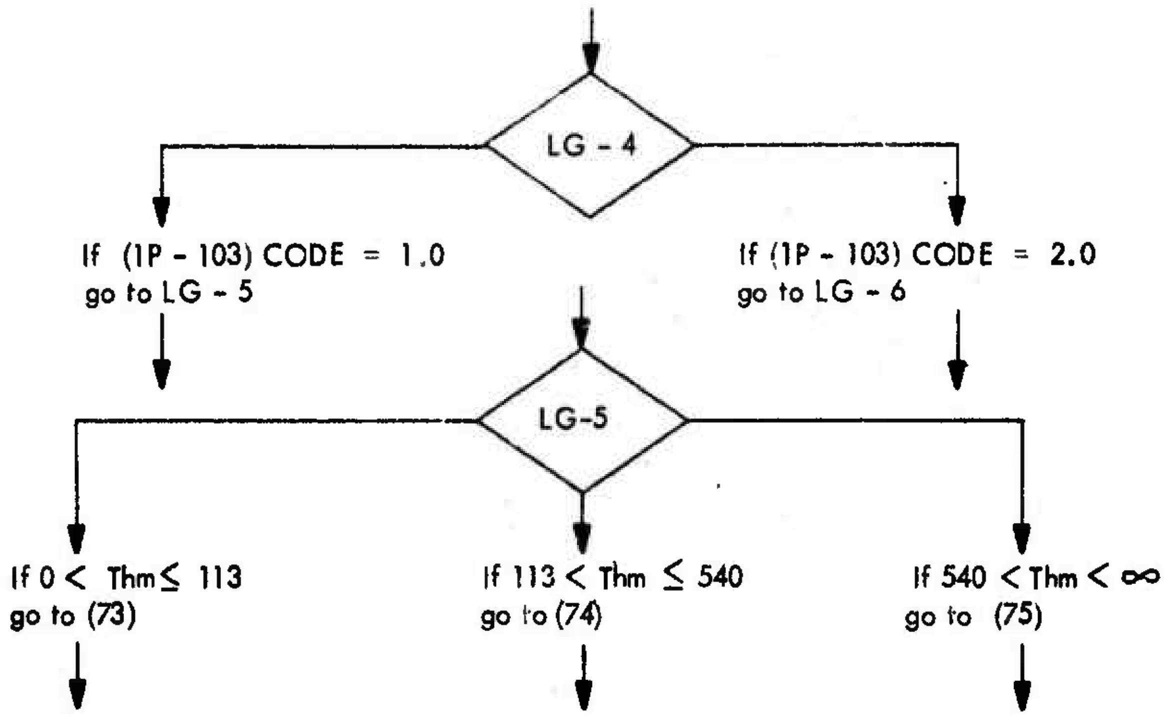
" " < " , reduce " " " " "

$$\epsilon i = \frac{Ntui}{1 + Ntui} \tag{70)*}$$

Then go to (71)

$$T'_1 = Thm - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \tag{71}$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \tag{72}$$



$$Kp = \frac{1}{\left[.1\,(Thm - T'_1)\right]} \left\{ \frac{49}{2} \left[(.1\,Thm)^2 - (.1T'_1)^2\right] - \frac{1}{3.47}\left[(.1\,Thm)^{3.47} - (.1T'_1)^{3.47}\right] \right. \tag{73}$$

Then go to (79)

$$Kp = \frac{1}{\left[.1\,(Thm - T'_1)\right]} \left\{ - \left[\frac{(.1\,Thm)^{2.708} - (.1T'_1)^{2.708}}{2.708}\right] + 9.551 \left[(.1\,Thm)^2 - (.1T'_1)^2\right] \right\} \tag{74}$$

Then go to (79)

$$Kp = 111.74 - \text{constant} \tag{75}$$

Then go to (79)

LG-6

If $0 < Thm \leq 210$ go to (76)

If $210 < Thm \leq 540$ go to (77)

If $540 < Thm < \infty$ go to (78)

$$Kp = \frac{1}{(Thm - T'i)} \left\{ \frac{2.765}{2} \left[(Thm)^2 - (T'i)^2 \right] - \left[\frac{(Thm)^{2.16} - (T'i)^{2.16}}{2.16} \right] \right\} \tag{76}$$

Then go to (79)

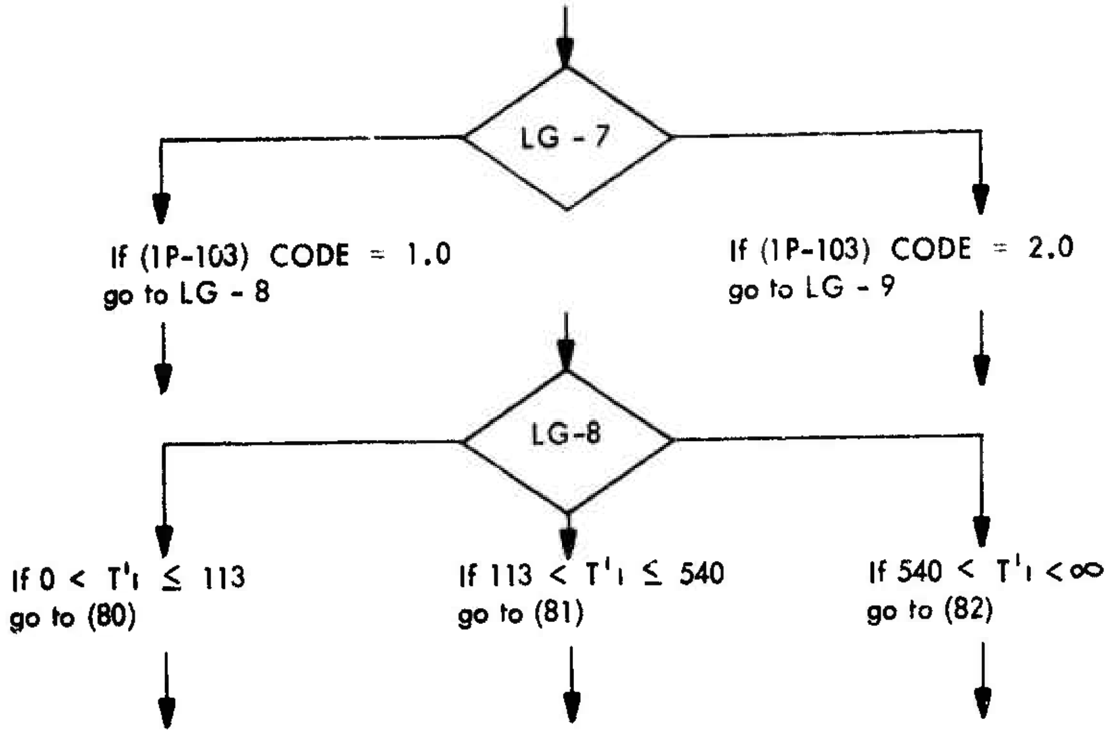
$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(Thm + T'i)/2 \right]^{\cdot} - 210}{330} \right) \right\} \tag{77}$$

Then go to (79)

$$KP = 92.25 = \text{constant} \tag{78}$$

Then go to (79)

$$K_{2-3} = Kp \ .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \tag{79*}$$



$$Kp = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ \frac{49}{2} \left[(.1T'_1)^2 - (.1T'_2)^2 \right] - \frac{1}{3.47} \left[(.1T'_1)^{3.47} - (.1T'_2)^{3.47} \right] \right\} \tag{80}$$

Then go to (86)

$$Kp = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ - \left[\frac{(.1T'_1)^{2.708} - (.1T'_2)^{2.708}}{2.708} \right] + 9.551 \left[(.1T'_1)^2 - (.1T'_2)^2 \right] \right\} \tag{81}$$

Then go to (86)

$$Kp = 111.74 = \text{constant} \tag{82}$$

Then go to (86)

LG-9

If $0 < T'_1 \leq 210$ go to (83)

If $210 < T'_1 \leq 540$ go to (84)

If $540 < T'_1 < \infty$ go to (85)

$$K_p = \frac{1}{(T'_1 - T'_2)} \left\{ \frac{2.765}{2} \left[(T'_1)^2 - (T'_2)^2 \right] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16} \right] \right\} \tag{83}$$

Then go to (86)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{\left[(T'_1 + T'_2)/2 \right] - 210}{330} \right) \right\} \tag{84}$$

Then go to (86)

$$K_p = 92.25 = \text{constant} \tag{85}$$

Then go to (86)

$$K_{3-4} = K_p \tag{86*}$$

LG-10

If (1P-103) CODE = 1.0 go to LG - 11

If (1P-103) CODE = 2.0 go to LG - 12

LG-11

If $0 < T'_2 \leq 113$ go to (87)

If $113 < T'_2 \leq 540$ go to (88)

If $540 < T'_2 < \infty$ go to (89)

$$K_p = \frac{1}{[.1(T'_2 - T_{cm})]}\left\{\frac{49}{2}\left[(.1\,T'_2)^2 - (.1\,T_{cm})^2\right] - \left[\frac{(.1\,T'_2)^{3.47} - (.1\,T_{cm})^{3.47}}{3.47}\right]\right\} \quad (87)$$

Then go to (93)

$$K_p = \frac{1}{[(.1(T'_2 - T_{cm})]}\left\{-\left[\frac{(.1\,T'_2)^{2.708} - (.1\,T_{cm})^{2.708}}{2.708}\right] + 9.551\left[(.1T'_2)^2 - (.1T_{cm})^2\right]\right\} \quad (88)$$

Then go to (93)

$$K_p = 111.74 = \text{constant} \quad (89)$$

Then go to (93)

LG-12

If $0 < T'_2 \leq 210$ go to (90)

If $210 < T'_2 \leq 540$ go to (91)

If $540 < T'_2 < \infty$ go to (92)

$$Kp = \frac{1}{(T'_2 - T_{cm})}\left\{\frac{2.765}{2}\left[(T'_2)^2 - (T_{cm})^2\right] - \left[\frac{(T'_2)^{2.16} - (T_{cm})^{2.16}}{2.16}\right]\right\} \quad (90)$$

Then go to (93)

$$Kp = 86.0 + \left\{6.25\left(\frac{\left[(T'_2 + T_{cm})/2\right] - 210}{330}\right)\right\} \quad (91)$$

Then go to (93)

$$Kp = 92.25 = \text{constant} \quad (92)$$

Then go to (93)

$$K_{4-5} = Kp \; .93061 \left[\frac{s - dh}{s - (dh/2)}\right] \quad (93)^*$$

$$U = \frac{1}{\frac{1}{h_{1-2}} + \frac{\ell_1}{k_{2-3}} + \frac{\ell_2}{k_{3-4}} + \frac{\ell_3}{k_{4-5}} + \frac{1}{h_{5-6}}} \quad (94)^*$$

$$ns = np + 1 \qquad (95)^{*}$$

$$\ell e = \frac{ns \cdot ts}{12} \qquad (96)$$

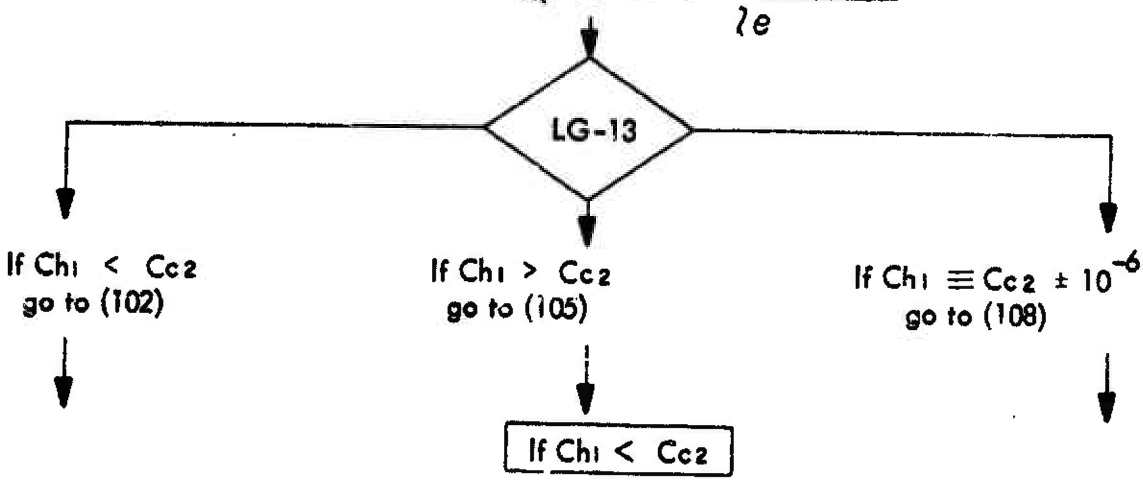
$$T\ell_1 = \frac{(T_{10} + T_{20})}{2} \qquad (97)$$

$$T\ell_2 = \frac{(T_9 + T_{21})}{2} \qquad (98)$$

$$AK\ell = \frac{\left[\left[x^2/F_s\right] - (X'Y')\right] + \left[(C-1)\ X'B'\right]}{144} \qquad (99)$$

$$\overline{K\ell} = \frac{7.27 \times 10^{-3}}{(T\ell_2 - T\ell_1)} \left[\frac{(T\ell_2)^{1.585} - (T\ell_1)^{1.585}}{1.585} \right] \qquad (100)$$

$$Q\ell = \frac{\overline{K\ell} \cdot AK\ell}{\ell e} \qquad (101)^{*}$$



$$\lambda = \frac{Q\ell}{3600 \quad C_{h1}} \tag{102}^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \tag{103}^*$$

TEST 7 - A

If (103) $\geq$ 1.0, stop and readout message .... "REDUCE Ntui"

" " < " , continue.

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left(C_{h1} / C_{c2} \right)}{1 - \epsilon} \right]}{1 - \left(C_{h1} / C_{c2} \right)} \tag{104}^*$$

Then go to LG - 14

$\boxed{\text{If } C_{h1} > C_{c2}}$

$$\lambda = \frac{Q\ell}{3600 \quad C_{c2}} \tag{105}^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \tag{106}^*$$

TEST 7 - B

If (106) $\geq$ 1.0, stop and readout message .... "REDUCE Ntui"

" " < " , continue

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(Cc2 / Chi \right)}{1 - \epsilon} \right]}{1 - \left(Cc2 / Chi \right)} \tag{107}*$$

Then go to LG - 14

$$\boxed{\text{If } Chi \equiv Cc2 \pm 10^{-6}}$$

$$\lambda = \frac{Q\ell}{3600\ Chi} \tag{108}*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \tag{109}*$$

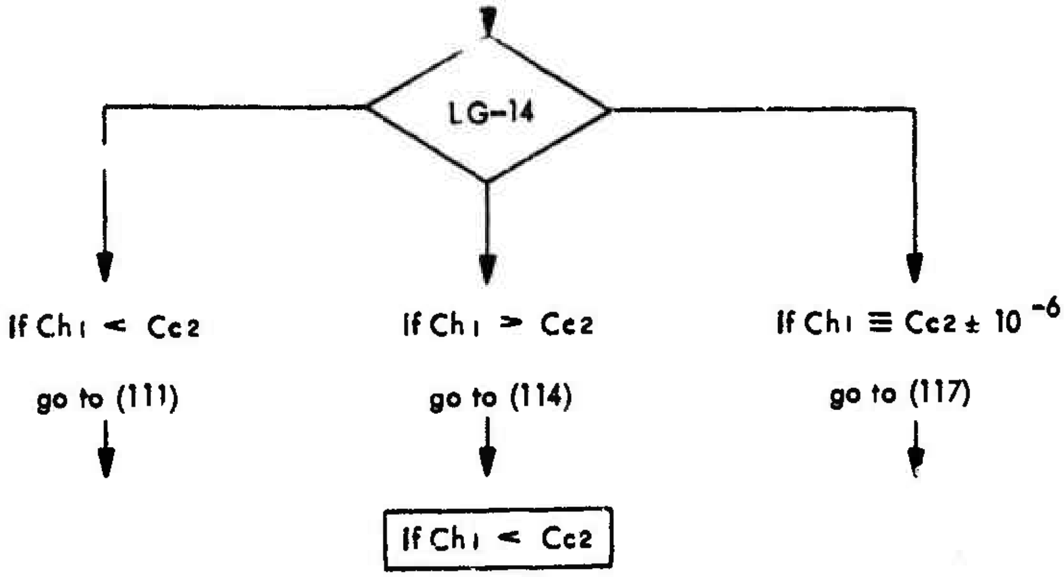
TEST 7 - C

If (109) $\geq$ 1.0, stop and readout message .... "REDUCE Ntui"

" " $<$ " , continue

$$Ntu = \frac{\epsilon}{1 - \epsilon} \tag{110}*$$

Then go to LG - 14



$$\text{Ax tot. hot side} = \frac{3600 \text{ Ntu. Ch1}}{U} \qquad (111)^*$$

$$\text{Axp} = \text{Ax}_1 \cdot \text{Af}_1 \qquad (112)^*$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{\text{Axp}} \qquad (113)$$

Note . . . . . If a fraction results, go to next higher whole number.

TEST 8-A

(113) must = (4) $^{+1}_{-0}$

If (113) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " " ".

Then go to (120)

$$\boxed{\text{If } Chi > Cc2}$$

$$\text{Ax tot. hot side} = \frac{3600\ Ntu \cdot Cc2}{U} \qquad (114)^{*}$$

$$Axp = Axi \cdot Afi \qquad (115)^{*}$$

$$\text{np calculated} = \frac{114\ \text{Ax tot. hot side}}{Axp} \qquad (116)$$

Note.....If a fraction results, go to next higher whole number.

Test 8 - B
(116) must = (4) $^{+1}_{-0}$
If (116) > (4), increase (4) and inerate from (4).
" < " , reduce " " " " ".

Then go to (120)

$$\boxed{\text{If } Chi \equiv Cc2 \pm 10^{-6}}$$

$$\text{Ax tot. hot side} = \frac{3600\ Ntu \cdot Chi}{U} \qquad (117)^{*}$$

$$Axp = Axi \cdot Afi \qquad (118)^{*}$$

$$\text{np calculated} = \frac{144 \quad \text{Ax tot. hot side}}{\text{Axp}} \qquad (119)$$

Note.....If a fraction results, go to next higher whole number.

Test 8 - C

(119) must = (4) $^{+1}_{-0}$

If (119) > (4), increases (4) and iterate from (4).

" " < ", reduce " " " " ".

Then go to (120)

$$\text{width X} = \text{equation (13) after closure} = \text{inches} \qquad (120)^*$$

$$\text{heigth Y} = \frac{X}{Fs} = \text{inches} \qquad (121)^*$$

$$\text{core length L} = \left[(np \cdot tp) + (ns \cdot ts)\right] = \text{inches} \qquad (122)^*$$

$$\text{core weight} = .098 \text{ np tp} \left\{\left[(XY) - (X'Y')\right] + \left[X\ B'\ (C-1)\right] + \left[Af_l\ (Ra+1)(1-\sigma)\right]\right\} +$$

$$.078 \text{ ns} \cdot \text{ts} \left[(XY) - (X'Y')\right] + \left[X'\ B'\ (C-1)\right] = \text{lbs} \qquad (123)^*$$

$$\text{header weight} = .196 \left[(XY) - Af_l\ (Ra+1) + \frac{XY}{8}\right] = \text{lbs} \qquad (124)^*$$

$$\text{total weight} = (123) + (124) \quad \text{lbs} \qquad (125)^*$$

$$\eta f = \cfrac{1}{1 + \left[\cfrac{h_{1-2} \left({}^{Axp}\!/_{Nh \cdot Y'_1} \right) (Y'_1)^2}{3 \; np \; K_{2-3} \left\{ X' \; tp \; .93061 \left[\cfrac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \qquad (126)*$$

Test 9
If (126)<.40, readout message..... "INCREASE (IP - 96).
" " >.60, " " " ..... "REDUCE (IP - 96).

Do <u>not</u> stop machine on TEST 9.

$$Av = \frac{\text{Ax tot. hot side}}{\left(\frac{X \cdot Y \cdot L}{1728}\right)} = ft^2/ft^3 \qquad (127)*$$

FINAL TEST
If (35) ≥ 540, stop machine
" " < ", call HX $(J)_{j=6.0}$ and continue.

The FLOW DIAGRAM for HX-5 is exactly similar to that of HX - 1.

APPENDIX VII

HX - 6 AND TURBINE 3PROGRAM --------CALL HX $(J)_{j=6.0}$

<u>Imputs:</u>

Call out numerical values from APPENDIX I, section VII.
Also call last result for T9, P9, T21 and P21 from output of HX - 5.

Initial numerical assumptions:

Equa. No:	Initial Value:
(4)	30.0
(5)	T9 + 10
(6)	1.02 P9
(13)	2.0
(41)	T21 + 10
(42)	.98 P21

Notes:

Readout last result of all equations marked with a star "*."
Do not stop machine at TEST 9.

$$s = \sqrt{.906894 \frac{dh^2}{\sigma}} \qquad (1)^*$$

$$n = \frac{4\sigma}{\pi\, dh^2} \qquad (2)^*$$

$$Ax1 = (n\,\pi dh\, tp) + 2(1-\sigma) \qquad (3)^*$$

np = assume

(Will be altered only by TEST 8) (4)*

T8 = assume

(Will be altered only by TEST 3) (5)*

P8 = assume

(Will be altered only by TEST 2) (6)

LG - 1

If $6 \leq T8 \leq 40$:

$$\bar{\nu}8 = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P8}/(T8/40)\right]}} \right] \left(\frac{T8}{P8} \right) \right\} \quad (7)$$

If $40 < T8 < \infty$:

$$\bar{\nu}8 = 2.863092 \left(\frac{T8}{P8} \right) \quad (8)$$

$$\mu 8 = 2.37888 \times 10^{-7} \, (T8)^{.643} \quad (9)$$

$$V8 = \frac{12 \; NRe1 \; \bar{\nu}8 \; \mu 8}{dh} \quad (10)^{*}$$

$$ah1 = \frac{144 \; W3 \; \bar{\nu}8}{V8} \quad (11)^{*}$$

$$Af1 = \frac{ah1}{\sigma} \quad (12)^{*}$$

X = assume

(Will be altered only by TEST 1) (13)*

$$X' = X - (2 \; Bx) \quad (14)^{*}$$

$$Y' = \frac{X}{Fs} - (2 \; By) \quad (15)^{*}$$

$$Y'_1 = \frac{Y' - \left[(C-1)\ B'\right] - Nh}{2\ (C-1)} \qquad (16)*$$

$$Af_1 \text{ calculated} = Nh\ (X'Y'_1) \qquad (17)$$

TEST 1

(17) must = (12) $\pm$ .001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " ".

$$Y'_2 = Y'_1 \cdot \frac{Ra}{2} \qquad (18)*$$

$$Y'_3 = Y'_1 \cdot Ra \qquad (19)*$$

$$\lambda_1 = \frac{Y'_1}{24} \qquad (20)$$

$$\lambda_2 = \frac{B'}{12} \qquad (21)$$

$$\lambda_3 = \frac{Y'_3}{12 \cdot Ra} \qquad (22)$$

$$\Delta P'_1 = \frac{370 \times 10^{-6}\ V_8^2}{\bar{\nu}_8} \sqrt{\frac{(tp/dh)}{NRe_1}} \qquad (23)$$

$$\Delta P_1 = np \cdot \Delta P'_1 \qquad (24)*$$

$$P8 \text{ calculated} = P9 + \Delta P_1 \qquad (25)$$

TEST 2

(25) must = (6) $\pm$ .001

If (25) > (6), increase (6) and iterate from (6).

" " < ", reduce " " " ".

Call cp subroutine and, with T8 and P8.....get

$$cp\ 8 = \quad (26)$$

Call cp subroutine and, with T21 and P21 ...get

$$cp\ 21 = \quad (27)$$

$$\overline{cp} = \frac{(cp\ 8 + cp\ 21)}{2} \quad (28)$$

$$\bar{\gamma} = \frac{1}{1 - \left(\frac{.496447487}{\overline{cp}} \right)} \quad (29)$$

$$\frac{T21}{T8} = 1 - \eta_t \left[1 - \left(P21/P8 \right)^{(\bar{\gamma} - 1)/\bar{\gamma}} \right] \quad (30)$$

$$T8\ \text{calculated} = \frac{T21}{(T21/T8)} \quad (31)$$

TEST 3

(31) must = (5) ± .001

If (31) > (5), increase (5) and iterate from (5).

" " < ", reduce " " " ".

$$\mu ml = \frac{8.55497 \times 10^{-4}}{(T8 - T9)} \left\{ \frac{(T8)^{1.643} - (T9)^{1.643}}{1.643} \right\} \qquad (32)$$

$$Kml = \frac{57.79 \times 10^{-3}}{\left[.00355\ (T8 - T9)\right]} \left\{ \frac{(.00355\ T8)^{1.642} - (.00355\ T9)^{1.642}}{1.642} \right\} \qquad (33)$$

$$Thm = \frac{\left| \dfrac{Kml}{57.79 \times 10^{-3}} \right|^{1/.642}}{.00355} \qquad (34)$$

$$Phm = \frac{(P8 + P9)}{2} \qquad (35)$$

Call cp subroutine and, with Thm and Phm. . . . . get

$$cphm = \qquad (36)$$

$$cht = cphm \cdot W_3 \qquad (37)^*$$

$$NPrl = \frac{cphm \cdot \mu ml}{Kml} \qquad (38)^*$$

$$NNu1 = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{NRe1 \cdot NPr1}\right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{NRe1 \cdot NPr1}\right]} \right)^{.8}} \right\} \qquad (39)^*$$

$$h_{1-2} = \frac{12\ NNu1 \cdot Km1}{dh} \qquad (40)^*$$

COLD SIDE:

$$T22 = \text{assume} \qquad (41)^*$$

(Will be altered only by TEST 6)

$$P22 = \text{assume} \qquad (42)^*$$

(Will be altered only by TEST 4)

LG - 2

If $6 \leq T22 \leq 40$

$$\bar{\nu}22 = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P22/(T22/40)}\right]}} \right] \left(\frac{T22}{P22} \right) \right\} \qquad (43)$$

If $40 < T22 < \infty$

$$\bar{\nu}22 = 2.863092 \left(\frac{T22}{P22} \right) \qquad (44)$$

$$\mu22 = 2.37388 \times 10^{-7}\ (T22)^{.643} \qquad (45)$$

$$ah2 = ah1 \cdot Ra \qquad (46)*$$

$$V22 = \frac{144\ W4\ \bar{\nu}22}{ah2} \qquad (47)*$$

$$NRe2 = \frac{V22 \cdot dh}{12\,\bar{\nu}22 \cdot \mu 22} \qquad (48)*$$

$$\Delta P_2' = \frac{370 \times 10^{-6}\ V^2{}_{22}}{\bar{\nu}\ 22} \sqrt{\frac{(tp/dh)}{NRe2}} \qquad (49)$$

$$\Delta P2 = np \cdot \Delta P_2' \qquad (50)*$$

$$P22 \text{ calculated} = P21 - \Delta P2 \qquad (51)$$

TEST 4
(51) must = (42) $\pm$ .001
If (51) $>$ (42), increase (42) and iterate from (42).
" " $<$ ", reduce " " " ".

TEST 5
If (51) $<$ 10, stop & readout message....."INCREASE Ra"
" " $\geq$ ', continue.

$$\mu m2 = \frac{8.55497 \times 10^{-4}}{(T22 - T21)} \left\{ \frac{(T22)^{1.643} - (T21)^{1.643}}{1.643} \right\} \qquad (52)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{\left[.00355\ (T22 - T21)\right]} \left\{ \frac{(.00355\ T22)^{1.642} - (.00355\ T21)^{1.642}}{1.642} \right\} \quad (53)$$

$$T_{cm} = \frac{\left(\dfrac{K_{m2}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (54)$$

$$P_{cm} = \frac{(P21 + P22)}{2} \quad (55)$$

Call cp subroutine, and, with Tcm and Pcm .... get

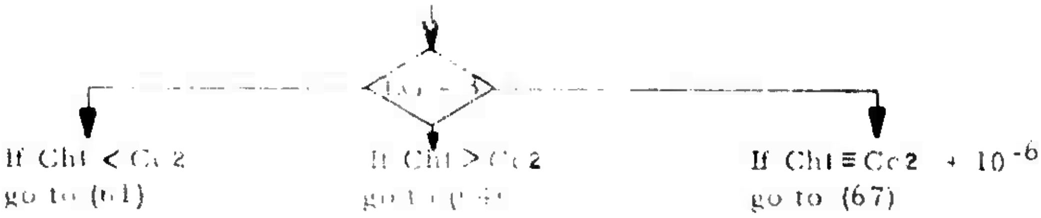
cpcm = (56)

$$C_{c2} = cpcm \cdot W4 \quad (57)^{*}$$

$$N_{Pr2} = \frac{cpcm \cdot \mu m2}{K_{m2}} \quad (58)^{*}$$

$$N_{Nu2} = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{N_{Re2} \cdot N_{Pr2}} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{N_{re2} \cdot N_{Pr2}} \right]^{.8}} \right)} \right\} \quad (59)^{*}$$

$$h_{5\text{-}6} = \frac{12\ N_{Nu2} \cdot K_{m2}}{dh} \quad (60)^{*}$$



If Ch1 < Cc2

$$T22 \text{ calculated} = T21 + \left[\frac{(T8 - T9)}{\left(Cc2 / Ch1 \right)} \right] \qquad (61)$$

TEST 6-A

(61) must = (41) $\pm$ .001

If (61) > (41), increase (41) and iterate from (41).

" " < ", reduce " " " ".

$$Ntui = \frac{\log_e \left[\frac{(T8 - T22)}{(T9 - T21)} \right]}{1 - \left(Ch1 / Cc2 \right)} \qquad (62)^*$$

$$\epsilon_i = \frac{1 - e^{- Ntui \left[1 - \left(Ch1 / Cc2 \right) \right]}}{1 - \left\{ \left(\frac{Ch1}{Cc2} \right) e^{- Ntui \left[1 - \left(Ch1 / Cc2 \right) \right]} \right\}} \qquad (63)^*$$

Then go to (70)

If Ch1 > Cc2

$$T22 \text{ calculated} = T21 + \left[\frac{(T8 - T9)}{\left(Ch1 / Cc2 \right)} \right] \qquad (64)$$

TEST 6 - B
(64) must = (41) $\pm$ .001
If (64) > (41), increase (41) and iterate from (41)
" " < ", reduce " " " " " .

$$Ntui = \frac{\log_e \left[\frac{(T8 - T22)}{(T9 - T21)} \right]}{1 - \left(Cc2 / Ch1 \right)} \qquad (65)^*$$

$$\epsilon i = \frac{1 - e^{- Ntui \left[1 - \left(Cc2 / Ch1 \right) \right]}}{1 - \left\{ \left(\frac{Cc2}{Ch1} \right) e^{- Ntui \left[1 - \left(Cc2 / Ch1 \right) \right]} \right\}} \qquad (66)^*$$

Then go to (70)

$\boxed{\text{If } Ch1 \cong Cc2 \pm 10^{-6}}$

$$T22 \text{ calculated} = T8 - (T9 - T21) \qquad (67)$$

TEST 6-C
(67) must = (41) $\pm$ .001
If (67) > (41), increase (41) and iterate from (41).
" " < ", reduce " " " " " .

$$Ntui = \frac{\left[\frac{(T8 - T9)}{(T8 - T21)}\right]}{1 - \left[\frac{(T8 - T9)}{(T8 - T21)}\right]} \tag{68*}$$

$$\epsilon i = \frac{Ntui}{1 + Ntui} \tag{69*}$$

Then go to (70)

$$T'_1 = Thm - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3}\right)(Thm - Tcm)\right] \tag{70}$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3}\right)(Thm - Tcm)\right] \tag{71}$$

LG - 4

If (1P-122) CODE = 1.0
go to LG - 5

If (1P-122) CODE = 2.0
go to LG - 6

LG-5

If $0 < Thm \leq 113$
go to (72)

If $113 < Thm \leq 540$
go to (73)

If $540 < Thm < \infty$
go to (74)

$$Kp = \frac{1}{\left[.1(Thm - T'_1)\right]}\left\{\frac{49}{2}\left[(.1Thm)^2 - (.1T'_1)^2\right] - \frac{1}{3.47}\left[(.1Thm)^{3.47} - (.1T'_1)^{3.47}\right]\right\} \tag{72}$$

Then go to (78)

$$Kp = \frac{1}{\left[.1(Thm - T'_1)\right]} \left\{ - \left[\frac{(.1Thm)^{2.708} - (.1T'_1)^{2.708}}{2.708} \right] + 9.551 \left[(.1Thm)^2 - (.1T'_1)^2 \right] \right\} \tag{73}$$

Then go to (78)

$$Kp = 111.74 = \text{constant} \tag{74}$$

Then go to (78)

LG - 6

If $0 < Thm \leq 210$ go to (75)

If $210 < Thm \leq 540$ go to (76)

If $540 < Thm < \infty$ go to (77)

$$Kp = \frac{1}{(Thm - T'_1)} \left\{ \frac{2.765}{2} \left[(Thm)^2 - (T'_1)^2 \right] - \left[\frac{(Thm)^{2.16} - (T'_1)^{2.16}}{2.16} \right] \right\} \tag{75}$$

Then go to (78)

$$Kp = 86.0 + \left\{ 6.25 \left(\frac{\left[(Thm + T'_1)/2\right] - 210}{330} \right) \right\} \tag{76}$$

Then go to (78)

$$Kp = 92.25 = \text{constant} \tag{77}$$

Then go to (78)

$$K_{2-3} = K_p \; .93061 \left[\frac{s - \text{[illegible]}}{s - (dh/2)} \right] \qquad (78)$$

LG - 7

If (1P - 122) CODE = 1.0
go to LG-8

If (1P - 122) CODE = 2.0
go to LG-9

LG - 8

If $0 < T'_1 \leq 113$
go to (79)

If $113 < T'_1 \leq 540$
go to (80)

If $540 < T'_1 < \infty$
go to (81)

$$K_p = \frac{1}{\left[.1\,(T'_1 - T'_2)\right]} \left\{ \frac{49}{2} \left[(.1\,T'_1)^2 - (.1\,T'_2)^2 \right] - \frac{1}{3.47} \left[(.1\,T'_1)^{3.47} - (.1\,T'_2)^{3.47} \right] \right\} \qquad (79)$$

Then go to (85)

$$K_p = \frac{1}{\left[.1(T'_1 - T'_2)\right]} \left\{ - \left[\frac{(.1\,T'_1)^{2.708} - (.1\,T'_2)^{2.708}}{2.708} \right] + 9.551 \left[(.1\,T'_1)^2 - (.1\,T'_2)^2 \right] \right\} \qquad (80)$$

Then go to (85)

$$K_p = 111.74 = \text{constant} \qquad (81)$$

Then go to (85)

LG - 9

If $0 < T'_1 \leq 210$ go to (82)

If $210 < T'_1 \leq 540$ go to (83)

If $540 < T'_1 < \infty$ go to (89)

$$K_p = \frac{1}{(T'_1 - T'_2)} \left\{ \frac{2.765}{2} \left[(T'_1)^2 - (T'_2)^2 \right] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16} \right] \right\} \qquad (82)$$

Then go to (85)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{\left[(T'_1 + T'_2)/2 \right] - 210}{330} \right) \right\} \qquad (83)$$

Then go to (85)

$$K_p = 92.25 = \text{constant} \qquad (84)$$

Then go to (85)

$$K_{3-4} = K_p \qquad (85)^*$$

LG - 10

If (1P - 122) CODE = 1.0 go to LG - 11

If (1P - 122) CODE = 2.0 go to LG - 12

LG-11

If $0 < T'_2 \leq 113$ go to (86)

If $113 < T'_2 \leq 540$ go to (87)

If $540 < T'_2 < \infty$ go to (88)

$$K_p = \frac{1}{\left[.1\,(T'_2 - T_{cm})\right]} \left\{ \frac{49}{2} \left[(.1\,T'_2)^2 - (.1\,T_{cm})^2 \right] - \frac{1}{3.47} \left[(.1\,T'_2)^{3.47} - (.1\,T_{cm})^{3.47} \right] \right\} \tag{86}$$

Then go to (92)

$$K_p = \frac{1}{\left[.1(T'_2 - T_{cm})\right]} \left\{ - \left[\frac{(.1T'_2)^{2.708} - (.1\,T_{cm})^{2.708}}{2.708} \right] + 9.551 \left[(.1\,T'_2)^2 - (.1\,T_{cm})^2 \right] \right\} \tag{87}$$

Then go to (92)

$$K_p = 111.74 = \text{constant} \tag{88}$$

Then go to (92)

LG-12

If $0 < T'_2 \leq 210$ go to (89)

If $210 < T'_2 \leq 540$ go to (90)

If $540 < T'_2 < \infty$ go to (91)

$$Kp = \frac{1}{(T'_2 - Tcm)} \left\{ \frac{2.765}{2} \left[(T'_2)^2 - (Tcm)^2 \right] - \left[\frac{(T'_2)^{2.16} - (Tcm)^{2.16}}{2.16} \right] \right\} \qquad (89)$$

Then go to (92)

$$Kp = 86.0 + \left\{ 6.25 \left(\frac{[(T'_2 + Tcm)/2] - 210}{330} \right) \right\} \qquad (90)$$

Then go to (92)

$$Kp = 92.25 = \text{constant} \qquad (91)$$

Then go to (92)

$$K_{4-5} = Kp \; .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \qquad (92)^*$$

$$U = \frac{1}{\left(\frac{1}{h_{1-2}} + \frac{l_1}{K_{2-3}} + \frac{l_2}{K_{3-4}} + \frac{l_3}{K_{4-5}} + \frac{1}{h_{5-6}} \right)} \qquad (93)^*$$

$$ns = np + 1 \qquad (94)^*$$

$$le = \frac{ns \cdot ts}{12} \qquad (95)$$

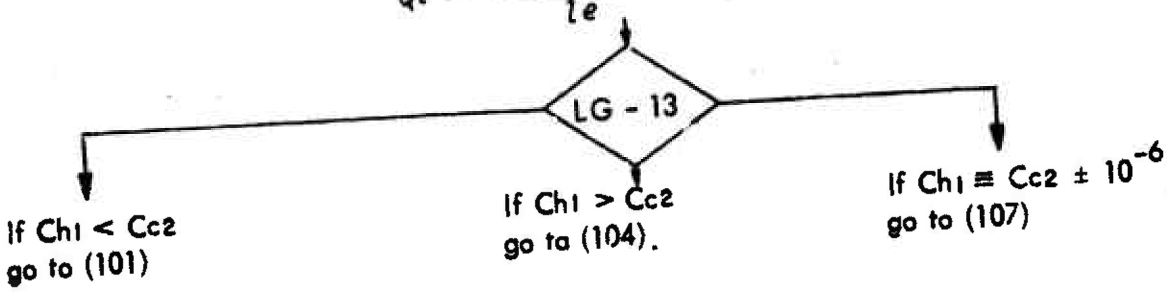
$$T_{l1} = \frac{(T9 + T21)}{2} \qquad (96)$$

$$T_{l2} = \frac{(T8 + T22)}{2} \qquad (97)$$

$$A_{kl} = \frac{\left[\left(X^2/F_s\right) - (X'Y')\right] + \left[(C-1)\,X'B'\right]}{144} \qquad (98)$$

$$\bar{K}_l = \frac{7.27 \times 10^{-3}}{(T_{l2} - T_{l1})}\left[\frac{(T_{l2})^{1.585} - (T_{l1})^{1.585}}{1.585}\right] \qquad (99)$$

$$Q_l = \frac{\bar{K}_l \cdot A_{kl}}{l_e} \qquad (100)^*$$



$\boxed{\text{If } Ch_1 < Cc_2}$

$$\lambda = \frac{Q_l}{3600\ Ch_1} \qquad (101)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1-\lambda}\right) \qquad (102)^*$$

TEST 7 - A

If (102) $\geq$ 1.0, stop and readout message .... "REDUCE BORDER DIMS. OR INCREASE t_s"

" " < ", continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(Chi/_{Cc2} \right)}{1 - \epsilon} \right]}{1 - \left(Chi/_{Cc2} \right)} \qquad (103)^*$$

Then go to LG - 14

$\boxed{\text{If } Chi > Cc2}$

$$\lambda = \frac{Q1}{3600\ Cc2} \qquad (104)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \qquad (105)^*$$

TEST 7-B

If (105) $\geq$ 1.0, stop & readout message..... OR INCREASE ts" "REDUCE BORDER DIMS.

" " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(Cc2/_{Chi} \right)}{1 - \epsilon} \right]}{1 - \left(Cc2/_{Chi} \right)} \qquad (106)^*$$

Then go to LG - 14

$\boxed{\text{If } Chi \equiv Cc2 \pm 10^{-6}}$

$$\lambda = \frac{Q1}{3600\ Chi} \qquad (107)^*$$

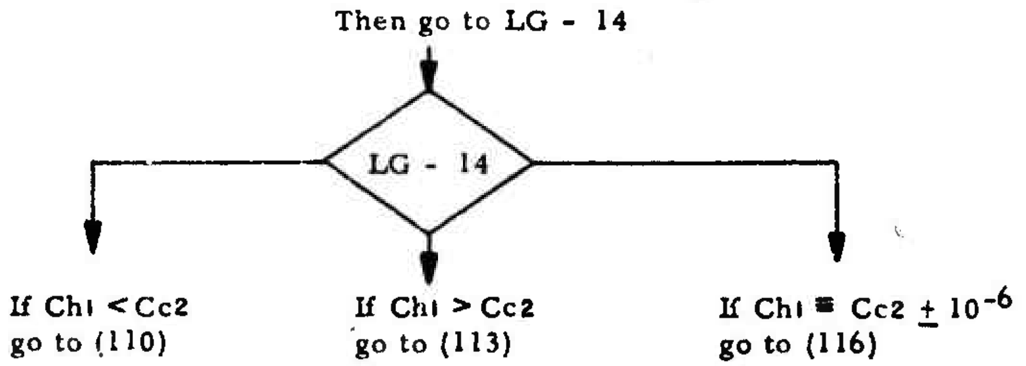
$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \qquad (108)^*$$

TEST 7-C

If (108) ≥ 1.0, stop & readout message.....OR INCREASE ts" "REDUCE BORDER DIMS.

" " < ", continue.

$$Ntu = \frac{\epsilon}{1 - \epsilon} \qquad (109)^*$$



$\boxed{\text{If Ch1} < \text{Cc2}}$

$$\text{Ax tot. hot side} = \frac{3600 \text{ Ntu Ch1}}{U} \qquad (110)^*$$

$$Axp = Ax1 \cdot Af1 \qquad (111)^*$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{Axp} \qquad (112)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8-A

(112) must = (4) $\pm{}^{1}_{0}$

If (112) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " ".

Then go to (119)

$\boxed{\text{If } Ch_1 > Cc_2}$

$$Ax \text{ tot. hot side} = \frac{3600 \ Ntu \ Cc_2}{U} \qquad (113)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (114)^*$$

$$np \text{ calculated} = \frac{144 \ Ax \text{ tot. hot side}}{Axp} \qquad (115)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8 - B

(115) must = (4) ${}^{+1}_{-0}$

If (115) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " " "

Then go to (119)

$\boxed{\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}}$

$$\text{Ax tot. hot side} = \frac{3600 \ \text{Ntu Chi}}{U} \tag{116*}$$

$$\text{Axp} = \text{Ax i} \cdot \text{Af i} \tag{117*}$$

$$\text{np calculated} = \frac{144 \ \text{Ax tot. hot side}}{\text{Axp}} \tag{118}$$

Note .... If a fraction results, go to next higher whole number.

TEST 8 - C

(118) must = (4) $^{+1}_{-0}$

If (118) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " " "

Then go to (119)

$$\text{width X} = \text{equation (13)} = \text{inches after closure.} \tag{119*}$$

$$\text{height Y} = \frac{X}{Fs} = \text{inches} \tag{120*}$$

$$\text{core length L} = \left[(np \cdot tp) + (ns \cdot ts) \right] = \text{inches} \tag{121*}$$

$$\text{core weight} = .098 \ np \ tp \left\{ \left[(XY) - (X'Y') \right] + \left[X'B'(C-1) \right] + \left[Af1 \ (Ra+1)(1-\sigma) \right] \right\} + .078 \ ns \ ts \left\{ \left[(XY) - (X'Y') \right] + \left[X'B' \ (C-1) \right] \right\} = \text{lbs} \tag{122*}$$

$$\text{header weight} = .196 \left[(XY) - Afl\,(Ra+1) + \frac{XY}{8} \right] - \text{lbs} \qquad (123)^*$$

$$\text{total weight} = (122) + (123) \quad \text{lbs} \qquad (124)^*$$

$$\eta f = \cfrac{1}{1 + \left[\cfrac{h_{1\text{-}2} \left({}^{Axp}\!/_{Nh} \cdot Y'_1 \right) (Y'_1)^2}{3\,np\,K_{2\text{-}3} \left\{ X'\,tp\,.93061 \left[\cfrac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \qquad (125)^*$$

TEST 9

If (125) < .40, readout message....."INCREASE (1P - 112)"
" " > .60 , " " ....."REDUCE (1P - 112)"

Do <u>not</u> stop machine on TEST 9.

$$Av = \frac{\text{Ax tot. hot side}}{\left(\frac{X \cdot Y \cdot L}{1728} \right)} = ft^2/ft^3 \qquad (126)^*$$

$$\Delta Ht_3 = \bar{c}p \quad T8\, \eta t \left[1 - \left({}^{P21}\!/_{P8} \right)^{(\bar{\gamma} - 1)/\bar{\gamma}} \right] = BTU/lb \qquad (127)^*$$

$$\text{Turbine output} = 1054.54\ Wt_3\ \Delta Ht_3 = \text{Watts} \qquad (128)^*$$

FINAL TEST

If (41) $\geq$ 540, stop machine

If (41) < 540, call HX (J) and continue.
j = 7.0

The FLOW DIAGRAM for HX - 6 is exactly similar to that of HX-2.

APPENDIX VIII

HX-7 PROGRAM .... CALL HX (J) $_j$ = 7.0 :

Inputs:

Call numerical values from APPENDIX I, Section VIII. Also call last result for T8, P8, T22 and P22 from output of HX-6.

Initial numerical assumptions:

Equa. No.	Initial value:
(4)	300.0
(5)	T8 + 150
(6)	1.02 P8
(13)	2.0
(35)	T22 + 150
(36)	.98 P22

Notes:

Readout last result of all equations marked with a star "*". Do not stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \quad \frac{dh^2}{\delta}} \tag{1*}$$

$$n = \frac{4\sigma}{\pi \, dh^2} \tag{2*}$$

$$Ax1 = (N \pi \, dh \;\; tp) + 2 \;\; (1 - \sigma) \tag{3*}$$

np = assume (4)*
(Will be altered only by TEST 8)

T7 = assume (5)*
(Will be altered only by TEST 6)

P7 = assume (6)*
(Will be altered only by TEST 2)

LG - 1

If $6 \leq T7 \leq 40$

$$\nu_7 = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P7}/\left(T7/40\right)\right]}} \right] \left(\frac{T7}{P7} \right) \right\} \tag{7}$$

If $40 < T7 < \infty$

$$\nu_7 = 2.863092 \left(\frac{T7}{P7} \right) \tag{8}$$

$$\mu_7 = 2.37888 \times 10^{-7} (T7)^{.643} \tag{9}$$

$$V_7 = \frac{12 \ N_{Re1} \ \bar{\nu}_7 \ \mu_7}{dh} \tag{10}*$$

$$ah_1 = \frac{144 \ W_4 \ \bar{\nu}_7}{V_7} \tag{11}*$$

$$Af_1 = \frac{ah_1}{\sigma} \tag{12}*$$

$$X = \text{assume} \tag{13}*$$

(Will be altered only by TEST 1)

$$X' = X - (2 \ Bx) \tag{14}*$$

$$Y' = \frac{X}{Fs} - (2 \ By) \tag{15}*$$

$$Y'_1 = \frac{Y' - \left[(C-1) \ B'\right] - Nh}{2 \ (C-1)} \tag{16}*$$

$$A_{fi} \text{ calculated} = N_h \ (X' Y_1') \tag{17}$$

TEST 1
(17) must = (12) ±.001
If (17) > (12), reduce (13) and iterate from (13).
" " < " , increase " " " " " .

$$Y'_2 = Y'_1 \ \frac{Ra}{2} \tag{18*}$$

$$Y'_3 = Y'_1 \cdot Ra \tag{19*}$$

$$l_1 = \frac{Y'_1}{24} \tag{20}$$

$$l_2 = \frac{B'}{12} \tag{21}$$

$$l_3 = \frac{Y'_3}{12 \cdot Ra} \tag{22}$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} \ V_7^2}{\bar{\nu}\, 7} \sqrt{\frac{(tp/dh)}{NRe_1}} \tag{23}$$

$$\Delta P_1 = np \cdot \Delta P'_1 \tag{24*}$$

$$P7 \text{ calculated} = P8 + \Delta P_l \qquad (25)$$

TEST 2
(25) must = (6) ±.001
If (25) > (6), increase (6) and iterate from (6).
" " < " , reduce " " " " " .

$$\mu m_l = \frac{8.55497 \times 10^{-4}}{(T7 - T8)} \left[\frac{(T7)^{1.643} - (T8)^{1.643}}{1.643} \right] \qquad (26)$$

$$Km_l = \frac{57.79 \times 10^{-3}}{\left[.00355\,(T7 - T8)\right]} \left[\frac{(.00355\,T7)^{1.642} - (.00355\,T8)^{1.642}}{1.642} \right] \qquad (27)$$

$$Thm = \frac{\left(\dfrac{Km_l}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \qquad (28)$$

$$Phm = \frac{(P7 + P8)}{2} \qquad (29)$$

Call cp subroutine and, with Thm and Phm .....get

$$cphm = \qquad (30)$$

$$Ch_l = cphm \cdot W4 \qquad (31)^*$$

$$NPr_1 = \frac{cphm \cdot \mu m_1}{Km_1} \tag{32}*$$

$$NNu_1 = 3.66 + \left\{ \frac{\left(\left[\frac{\frac{.104}{(tp/dh)}}{NRe_1 \cdot NPr_1}\right]\right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe_1 \cdot NPr_1}\right]^{.8}}\right)} \right\} \tag{33}*$$

$$h_{1-2} = \frac{12 \; NNu_1 \cdot Km_1}{dh} \tag{34}*$$

<u>**COLD SIDE:**</u>

T23 = assume (35)*

(Will be altered only by TEST 5)

P23 = assume (36)*

(Will be altered only by TEST 3)

LG-2

If $6 \leq T23 \leq 40$

$$\bar{\nu}_{23} = \left\{ \left[\frac{2.765}{e^{.03\left[\sqrt[3]{P23}/(T23/40)\right]}} \right] \left(\frac{T23}{P23} \right) \right\} \qquad (37)$$

If $40 < T23 < \infty$

$$\bar{\nu}_{23} = 2.863092 \; \frac{T23}{P23} \qquad (38)$$

$$ah_2 = ah_1 \cdot Ra \qquad (39)^*$$

$$V_{23} = \frac{144 \; W_4 \; \bar{\nu}_{23}}{ah_2} \qquad (40)^*$$

$$\mu_{23} = 2.37888 \times 10^{-7} \; (T23)^{.643} \qquad (41)$$

$$NRe_2 = \frac{V_{23} \cdot dh}{12 \; \bar{\nu}_{23} \cdot \mu_{23}} \qquad (42)^*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} \; V_{23}^{\,2}}{\bar{\nu}_{23}} \sqrt{\frac{(tp/dh)}{NRe_2}} \qquad (43)$$

$$\Delta P_2 = np \cdot \Delta P'_2 \qquad (44)^*$$

$$P23\ \text{calculated} = P22 - \Delta P_2 \tag{45}$$

TEST 3
(45) must = (36) ±.001
If (45) > (36), increase (36) and iterate from (36).
" " < " , reduce " " " " " .

TEST 4
If (45) < 10, stop & readout message ..... "DECREASE NRei or INCREASE Ra "
" " ≥ 10, continue.

$$\mu m2 = \frac{8.55497 \times 10^{-4}}{(T23 - T22)} \left[\frac{(T23)^{1.643} - (T22)^{1.643}}{1.643} \right] \tag{46}$$

$$Km2 = \frac{57.79 \times 10^{-3}}{\left[.00355\ (T23 - T22)\right]} \left[\frac{(.00355\ T23)^{1.642} - (.00355\ T22)^{1.642}}{1.642} \right] \tag{47}$$

$$Tcm = \frac{\left(\dfrac{Km2}{57.79 \times 10^{-3}}\right)^{1/.642}}{.00355} \tag{48}$$

$$Pcm = \frac{(P22 + P23)}{2} \tag{49}$$

Call cp subroutine and, with Tcm and Pcm .....get

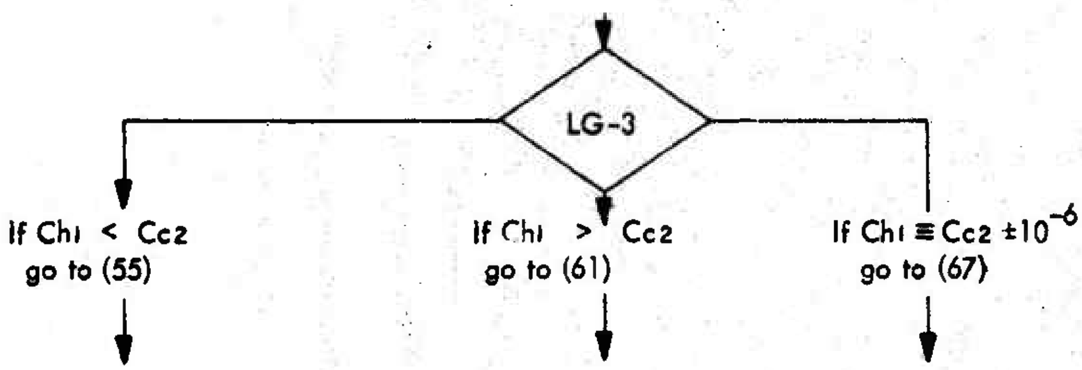
$$cpcm = \leftarrow \tag{50}$$

$$Cc2 = cpcm \cdot W4 \tag{51*}$$

$$Npr2 = \frac{cpcm \cdot \mu\, m2}{Km2} \tag{52*}$$

$$NNu2 = 3.66 + \left\{ \frac{\left(\dfrac{.104}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)}{1 + \left(\dfrac{.016}{\left[\dfrac{(tp/dh)}{NRe2 \cdot NPr2} \right]^{.8}} \right)} \right\} \tag{53*}$$

$$h_{5-6} = \frac{12\, NNu2 \cdot Km2}{dh} \tag{54*}$$



If Chi < Cc2

$$\nabla 1 = (T8 - T22)\; e^{Ntui \left[1 - \left(Chi / Cc2 \right) \right]} \tag{55}$$

$$\Delta X = \frac{\nabla 1 - (T8 - T22)}{\left(\frac{Cc2}{Ch1}\right) - 1} \qquad (56)$$

$$\Delta Y = \left(\frac{Cc2}{Ch1}\right) \cdot \Delta X \qquad (57)$$

$$T23 \text{ calculated} = T22 + \Delta X \qquad (58)$$

TEST 5-A
(58) must = (35) ±.001
If (58) > (35), increase (35) and iterate from (35).
" " < " , reduce " " " " " .

$$T7 \text{ calculated} = T8 + \Delta Y \qquad (59)$$

TEST 6-A
(59) must = (5) ±.001
If (59) > (5), increase (5) and iterate from (5).
" " < " , reduce " " " " ".

$$\epsilon i = \frac{1 - e^{-Ntui\left[1 - (Ch1/Cc2)\right]}}{1 - \left\{\left(\frac{Ch1}{Cc2}\right) e^{-Ntui\left[1 - (Ch1/Cc2)\right]}\right\}} \qquad (60)^*$$

Then go to (71)

$$\boxed{\text{If } C_{hi} > C_{c2}}$$

$$\nabla 1 = (T8 - T22)\, e^{N_{tui}\left[1 - \left(C_{c2}/C_{hi}\right)\right]} \tag{61}$$

$$\Delta X = \frac{\nabla 1 - (T8 - T22)}{\left(\frac{C_{hi}}{C_{c2}}\right) - 1} \tag{62}$$

$$\Delta Y = \left(\frac{C_{hi}}{C_{c2}}\right) \cdot \Delta X \tag{63}$$

$$T23 \text{ calculated} = T22 + \Delta X \tag{64}$$

TEST 5-B
(64) must = (35) ±.001
If (64) > (35), increase (35) and iterate from (35).
" " < " , reduce " " " " " .

$$T7 \text{ calculated} = T8 + \Delta Y \tag{65}$$

TEST 6-B
(65) must = (5) ±.001
If (65) > (5), increase (5) and iterate from (5).
" " < " , reduce " " " " " .

$$\epsilon i = \frac{1 - e^{-N_{tui}\left[1 - (C_{c2}/C_{hi})\right]}}{1 - \left\{\left(\frac{C_{c2}}{C_{hi}}\right) e^{-N_{tui}\left[1 - (C_{c2}/C_{hi})\right]}\right\}} \tag{66*}$$

Then go to (71)

$$\boxed{\text{If } Ch1 \cong Cc2 \pm 10}$$

$$Z = \frac{(T8 - T22)}{1 - \left(\frac{Ntui}{1 + Ntui}\right)} \qquad (67)$$

$$T23 \text{ calculated} = (T22 + Z) - (T8 - T22) \qquad (68)$$

TEST 5 - C

(68) must = (35) ± .001

If (68) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " " .

$$T7 \text{ calculated} = T22 + Z \qquad (69)$$

TEST 6 - C

(69) must = (5) ± .001

If (69) > (5) , increase (5) and iterate from (5).

" " < " , reduce " " " " ".

$$\epsilon i = \frac{Ntui}{1 + Ntui} \qquad (70)^*$$

Then go to (71)

$$T'_1 = Thm - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3}\right)(Thm - Tcm)\right] \qquad (71)$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3}\right)(Thm - Tcm)\right] \qquad (72)$$

LG - 4

If (IP - 139) CODE = 1.0
go to LG - 5

If (IP - 139) CODE = 2.0
go to LG - 6

LG - 5

If $0 < Thm \leq 113$ to to (73)

If $113 < Thm \leq 540$ go to (74)

If $540 < Thm < \infty$ go to (75)

$$Kp = \frac{1}{\left[.1\,(Thm - T'_1)\right]} \left\{ \frac{49}{2} \left[(.1\,Thm)^2 - (.1T'_1)^2 \right] - \frac{1}{3.47} \left[(.1\,Thm)^{3.47} - (.1\,T'_1)^{3.47} \right] \right\} \quad (73)$$

Then go to (79)

$$Kp = \frac{1}{\left[.1\,(Thm - T'_1)\right]} \left\{ - \left[\frac{(.1\,Thm)^{2.708} - (.1\,T'_1)^{2.708}}{2.708} \right] + 9.551 \left[(.1\,Thm)^2 - (.1\,T'_1)^2 \right] \right\} \quad (74)$$

Then go to (79)

$$Kp = 111.75 = \text{constant} \quad (75)$$

Then go to (79)

LG - 6

If $0 < Thm \leq 210$ go to (76)

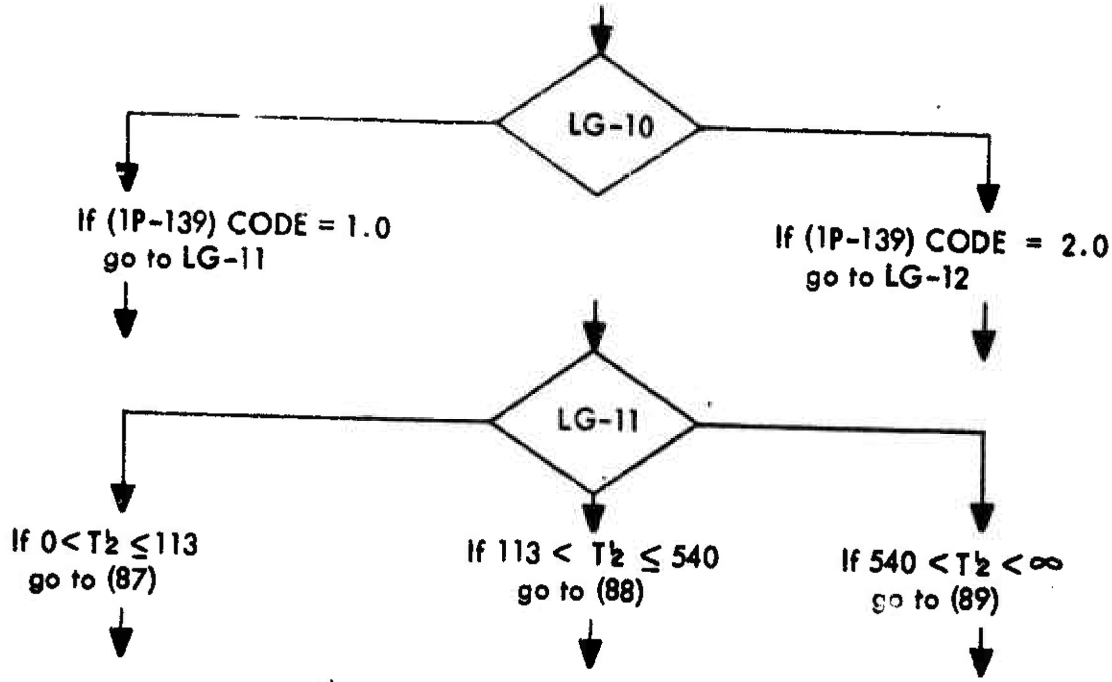
If $210 < Thm \leq 540$ go to (77)

If $540 < Thm \leq \infty$ go to (78)

$$Kp = \frac{1}{(Thm - T'_1)} \left\{ \frac{2.765}{2} \left[(Thm)^2 - (T'_1)^2 \right] - \left[\frac{(Thm)^{2.16} - (T'_1)^{2.16}}{2.16} \right] \right\} \quad (76)$$

Then go to (79)

$$ {}_{3-4}K = K_p \tag{86*} $$



$$ K_p = \frac{1}{\left[.1(T_2' - T_{cm})\right]} - \left\{ \frac{49}{2}\left[(.1T_2')^2 - (.1\,T_{cm})^2\right] - \frac{1}{3.47}\left[(.1T_2')^{3.47} - (.1\,T_{cm})^{3.47}\right] \right\} \tag{87} $$

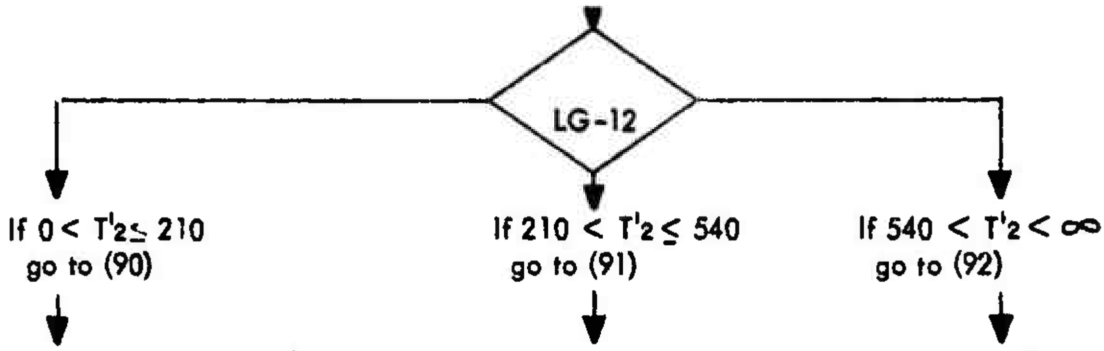
Then go to (93)

$$ K_p = \frac{1}{\left[.1(T_2' - T_{cm})\right]} \left\{ - \left[\frac{(.1T_2')^{2.708} - (.1\,T_{cm})^{2.708}}{2.708} \right] + 9.551\left[(.1T_2')^2 - (.1\,T_{cm})^2\right] \right\} \tag{88} $$

Then go to (93)

$$ K_p = 111.74 = \text{constant} \tag{89} $$

Then go to (93)



$$K_p = \frac{1}{(T'_2 - T_{cm})} \left\{ \frac{2.765}{2} \left[(T'_2)^2 - (T_{cm})^2 \right] - \left[\frac{(T'_2)^{2.16} - (T_{cm})^{2.16}}{2.16} \right] \right\} \tag{90}$$

Then go to (93)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{\left[(T'_2 + T_{cm})/2 \right] - 210}{330} \right) \right\} \tag{91}$$

Then go to (93)

$$K_p = 92.25 = \text{constant} \tag{92}$$

Then go to (93)

$$K_{4-5} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \qquad (93)^*$$

$$U = \frac{1}{\left(\frac{1}{h_{1-2}} \quad \frac{\ell_1}{K_{2-3}} \quad \frac{\ell_2}{K_{3-4}} \quad \frac{\ell_3}{K_{4-5}} \quad \frac{1}{h_{5-6}} \right)} \qquad (94)^*$$

$$ns = np + 1 \qquad (95)^*$$

$$\ell_e = \frac{n_s \cdot t_s}{12} \qquad (96)$$

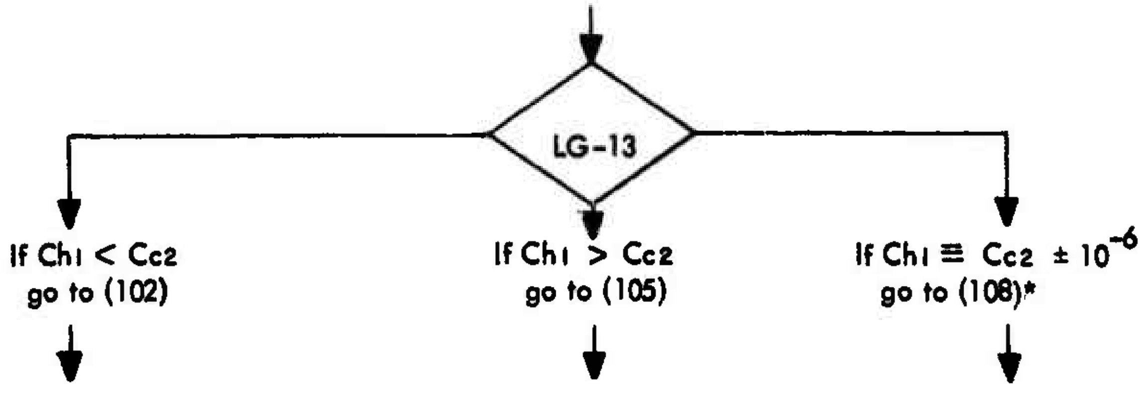
$$T\ell_1 = \frac{(T8 + T22)}{2} \qquad (97)$$

$$T\ell_2 = \frac{(T7 + T23)}{2} \qquad (98)$$

$$A_{\kappa\ell} = \frac{\left[\left(X2/F_s\right) - (X'\,Y')\right] + \left[(C-1)\,X'\,B'\right]}{144} \qquad (99)$$

$$\overline{K\ell} = \frac{7.27 \times 10^{-3}}{(T\ell_2 - T\ell_1)} \left[\frac{(T\ell_2)^{1.585} - (T\ell_1)^{1.585}}{1.585} \right] \qquad (100)$$

$$Q\ell = \frac{\overline{K\ell} \cdot A_{\kappa\ell}}{\ell_e} \qquad (101)^*$$



$\boxed{\text{If } Ch_1 < Cc_2}$

$$\lambda = \frac{Q\, l}{3600\ Ch_1} \qquad (102)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \qquad (103)^*$$

TEST 7-A
If (103) $\geq$ 1.0, stop & readout message .... "REDUCE Ntui"
"   "   < " , continue.

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left(Ch_1 / Cc_2 \right)}{1 - \epsilon} \right]}{1 - \left(Ch_1 / Cc_2 \right)} \qquad (104)^*$$

Then go to LG-14.

$\boxed{\text{If } Ch_1 > Cc_2}$

$$\lambda = \frac{Q\, l}{3600\ Cc_2} \qquad (105)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \qquad (106)^*$$

TEST 7-B
If (106) $\geq$ 1.0, stop & readout message .... "REDUCE Ntui "
"   "   < " , continue.

$$Ntu = \frac{\log_e \left[\dfrac{1 - \epsilon \left(Cc2/Ch1 \right)}{1 - \epsilon} \right]}{1 - \left(Cc2/Ch1 \right)} \qquad (107)^*$$

Then go to LG-14

$\boxed{\text{If } Ch1 \equiv Cc2 \pm 10^{-6}}$

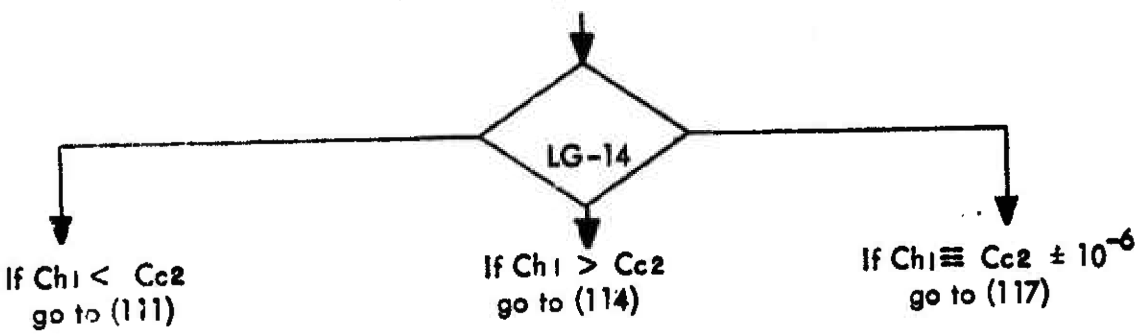
$$\lambda = \frac{Q\,l}{3600\ Ch1} \qquad (108)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \qquad (109)^*$$

TEST 7-C
If (109) ≥ 1.0, stop & readout message ..... "REDUCE Ntui"
" " < " , continue.

$$Ntu = \frac{\epsilon}{1 - \epsilon} \qquad (110)^*$$

Then go to LG-14



$\boxed{\text{If } C_{h1} < C_{c2}}$

$$Ax \text{ tot. hot side} = \frac{3600 \; Ntu \; C_{h1}}{U} \qquad (111)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (112)^*$$

$$np \text{ calculated} = \frac{144 \; Ax \text{ tot. hot side}}{Axp} \qquad (113)$$

Note.... If a fraction results, go to next higher whole number.

TEST 8-A
(113) must = (4) $^{+1}_{-0}$
If (113) $\geq$ (4), increase (4) and iterate from (4).
" " < " , reduce ". " " " ".

Then go to (120)

$\boxed{\text{If } C_{h1} > C_{c2}}$

$$Ax \text{ tot. hot side} = \frac{3600 \; Ntu \; C_{c2}}{U} \qquad (114)^*$$

$$Axp = Ax_1 \cdot Af_1 \qquad (115)^*$$

$$np \text{ calculated} = \frac{144 \ Ax \text{ tot. hot side}}{Axp} \tag{116}$$

Note..... If a fraction results, go to next higher whole number.

TEST 8-B

(116) must = (4) $\begin{smallmatrix}+1 \\ -0\end{smallmatrix}$

If (116) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " " .

Then go to (120)

$$\boxed{\text{If } Ch_1 \equiv Cc_2 \quad \pm 10^{-6}}$$

$$Ax \text{ tot. hot side} = \frac{3600 \ Ntu \ Ch_1}{U} \tag{117*}$$

$$Axp = Ax_1 \cdot Af_1 \tag{118*}$$

$$np \text{ calculated} = \frac{144 \ Ax \text{ tot. hot side}}{Axp} \tag{119}$$

Note..... If a fraction results, go to next higher whole number.

TEST 8-C

(119) must = (4) $\begin{smallmatrix}+1 \\ -0\end{smallmatrix}$

If (119) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " " .

Then go to (120)

$$\text{width } X = \text{equation (13) after closure} = \text{inches} \qquad (120)^*$$

$$\text{height } Y = \frac{X}{Fs} = \text{inches} \qquad (121)^*$$

$$\text{core length } L = \left[(np \cdot tp) + (ns \cdot ts)\right] = \text{inches} \qquad (122)^*$$

$$\text{core weight} = .098\ np\ tp \left\{ \left[(XY) - (X'Y')\right] + \left[X'B'\ (C-1)\right] + \left[Af\imath\ (Ra+1)\ (1-\sigma)\right] \right\} +$$

$$.078\ ns\ ts \left\{ \left[(XY) - (X'Y')\right] + \left[X'B'\ (C-1)\right] \right\} = \text{lbs} \qquad (123)^*$$

$$\text{header weight} = .196 \left[(XY) - Af\imath\ (Ra+1) + \frac{XY}{8}\right] = \text{lbs} \qquad (124)^*$$

$$\text{total weight} = (123) + (124) = \text{lbs} \qquad (125)^*$$

$$\eta f = \cfrac{1}{1 + \left[\cfrac{h_{1-2}\ (Axp/Nh \cdot Y\imath')\ (Y\imath')2}{3\ np\ {}_{2-3}K_3 \left\{ X'\ tp\ .93061 \left[\cfrac{s - dh}{s - (dh/2)}\right] \right\}} \right]} \qquad (126)^*$$

TEST 9
If (126) < .40, readout message ....."INCREASE (1P - 132)"
" " > .60, " " ....."REDUCE " "

Do not stop machine on TEST 9

$$A_V \quad \frac{A_x \text{ tot. hot side}}{\left(\frac{X \cdot Y \cdot L}{1728}\right)} = ft^2 / ft^3 \qquad (127)^*$$

FINAL TEST

Final test does not apply ..... STOP after (127).

The FLOW DIAGRAM for HX-7 is exactly similar to that of HX-1.

APPENDIX IX

BASIC FORTRAN MACHINE LISTING:

The following comprises the Fortran machine listing for the complete program.

```
C      MAIN PROGRAM
C      FOR USE WITH ANALYTICAL PROGRAM FOR CRYOGENIC TURBOMACHINE
C      SYSTEMS
C      VERSION 17JULY  1970
        DIMENSION S(8),AN(8),AX1(8),AH1(8),AF1(8)
        DIMENSION XPR(8),YPR(8),ANP(8),DP1(8),ANPR1(8)
        DIMENSION ANPR(8),ANNU1(8),H12(8),ANRE2(8)
        DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
        DIMENSION AK23(8),AK34(8),AK45(8),U(8)
        DIMENSION AXTHS(8),AXP(8),EI(8),ANS(8)
        DIMENSION QL(8),AE(8),WX(8),HY(8),ALL(8)
        DIMENSION CW(8),HW(8),TW(8),ANF(8),AV(8)
        DIMENSION CH1(8),CC2(8),S2(8),AN2(8),AH2(8)
        DIMENSIØN K1(8),K21(8),K3(8),K4(8)
        DIMENSIØN ANTU(8),DHT(8),AKWT(8),ANTU1(8),AKP(5),TLX(5)
        DIMENSIØN XPR1(8),YPR1(8),YPR2(8),YPR3(8)
        DIMENSIØN ALAM(5),TX(8)
        CØMMON S,AN,AX1,AH1,AF1,XPR,YPR,ANP,DP1,ANPR1,ANPR
        CØMMON ANNU1,H12,ANRE2,DP2,ANPR2,ANNU2,H56, AK23,AK34
        CØMMON AK45,U,AXTHS,AXP,EI,ANS,QL,AE,WX,HY,ALL,CW,HW,TW
        CØMMON ANF,AV,CH1,CC2,S2,AN2,AH2,K1,K21,K3,K4
        CØMMØN T14,P14,VB14,H14,S14,W1
        CØMMØN T15,P15,VB15,H15,S15
        CØMMØN T16,P16,VB16,H16,S16
        CØMMØN DH,TP,SIG,ANRE1,C,FS,RF,ANTU,TS
        CØMMØN ANT1,DH2,SIG1,SIG2,W2,WT1
        CØMMØN DHT,AKWT,ANTU1,MAT,TLX
        CØMMØN BX,BY,ANH,ANC
        CØMMØN XPR1,YPR1,YPR2,YPR3
        CØMMØN ALAM,TX,BPR,RA
1      FØRMAT(1X,18HPRØGRAM INPUT DATA)
2      FØRMAT(1X,11H1 LØAD DATA)
3      FØRMAT(1X,22H     AT JT VALVE INLET:)
4      FØRMAT(1X,5H T14=F15.8,2X,5HDEG.R)
5      FØRMAT(1X,5H P14=F15.8,2X,4HPSIA)
6      FØRMAT(1X,6H VB14=F15.8,1X,9HCU.FT./LB)
7      FØRMAT(1X,5H H14=F15.8,2X,6HBTU/LB)
8      FØRMAT(1X,5H S14=F15.8,2X,12HBTU/LB-DEG.R)
9      FØRMAT(1X,4H W1=F15.8)
10     FØRMAT(/1X,70(1H*))
11     FØRMAT(1X,21H     AT JT VALVE EXIT:)
12     FØRMAT(1X,5H T15=F15.8,2X,5HDEG.R)
13     FØRMAT(1X,5H P15=F15.8,2X,4HPSIA)
14     FØRMAT(1X,6H VB15=F15.8,1X,9HCU.FT./LB)
15     FØRMAT(1X,5H H15=F15.8,2X,6HBTU/LB)
16     FØRMAT(1X,5H S15=F15.8,2X,12HBTU/LB-DEG.R)
17     FØRMAT(1X,17H     AT LØAD EXIT:)
18     FØRMAT(1X,5H T16=F15.8,2X,5HDEG.R)
19     FØRMAT(1X,5H P16=F15.8,2X,4HPSIA)
20     FØRMAT(1X,6H VB16=F15.8,1X,9HCU.FT./LB)
```

```
21     FØRMAT(1X,5H H16=F15.8,2X,6HBTU/LB)
22     FØRMAT(1X,5H S16=F15.8,2X,12HBTU/LB-DEG.R)
23     FØRMAT(1X,9H HX1 DATA)
24     FØRMAT(1X,5H T17=F15.8,2X,5HDEG.R)
25     FØRMAT(1X,5H  DH=F15.8,2X,6HINCHES)
26     FØRMAT(1X,4H TP=F15.8)
27     FØRMAT(1X,4H TS=F15.8)
28     FØRMAT(1X,7H SIGMA=F15.8)
29     FØRMAT(1X,6H NRE1=F15.8)
30     FØRMAT(1X,3H C=F15.8)
31     FØRMAT(1X,4H FS=F15.8)
32     FØRMAT(1X,4H RF=F15.8)
34     FØRMAT(1X,16H ØUTPUT FRØM HX1)
55      FØRMAT(1X,25HØUTPUT FRØM HX2&TURBINE I)
56      FØRMAT(1X,5H P12=F15.8,5H V12=F15.8,5H T12=F15.8)
57      FØRMAT(1X,5H P13=F15.8,5H V13=F15.8,5H T13=F15.8)
58      FØRMAT(1X,5H P17=F15.8,5H V17=F15.8,5H T17=F15.8)
59      FØRMAT(1X,5H P18=F15.8,5H V18=F15.8,5H T18=F15.8)
60      FØRMAT(1X,5H V14=F15.8)
61      FØRMAT(1X,5H NT1=F15.8)
62      FØRMAT(1X,5H DH2=F15.8,2X,6HINCHES)
63      FØRMAT(1X,8H SIGMA1=F15.8)
64      FØRMAT(1X,8H SIGMA2=F15.8)
65      FØRMAT(1X,3H WT,I1,1H=F15.8)
66      FØRMAT(1X,2H W,I1,1H=F15.8)
67      FØRMAT(1X,9H HX2 DATA)
68      FØRMAT(1X,5H V13=F15.8)
69      FØRMAT(12I2)
70      FØRMAT(1X,9H HX3 DATA)
71      FØRMAT(1X,16H ØUTPUT FRØM HX3)
72      FØRMAT(1X,5H NTU=F15.8)
C      LØAD DATA:AT JT VALVE INLET
        ØPEN[3,INPUT,/APDAT/]
100     FØRMAT(5(1X,F15.8))
101     FØRMAT(2I5)
102     FØRMAT(1X,15HT14,P14,T16,P16)
103     FØRMAT(1X,9HT17,ANRE1)
104     FØRMAT(1X,12HGØ=1,NØGØ=-1)
105     FØRMAT(1X,10HANT1,ANRE1)
106     FØRMAT(1X,11HANRE1,ANTU1)
       I1=0
       I2=1
        I3=3
        TLX(1)=113.
        TLX(2)=210.
        TLX(3)=0.
        TLX(4)=0.
        TLX(5)=0.
        READ(I3,100)T14,P14,H14,S14
        READ(I1,101) KR,MAT
```

```
C                  AT JT VALVE EXIT
      READ(I3,100)T15,P15,H15,S15
C                  AT LOAD EXIT
      READ(I3,100)T16,P16,H16,S16
      READ(I3,100)DHL,ALW
      WRITE(I2, 1)
      WRITE(I2, 2)
      WRITE(I2, 3)
      WRITE(I2, 4)T14
      WRITE(I2, 5)P14
      WRITE(I2, 6)VB14
      WRITE(I2, 7)H14
      WRITE(I2, 8)S14
      WRITE(I2, 9)W1
      WRITE(I2,10)
      WRITE(I2,11)
      WRITE(I2,12)T15
      WRITE(I2,13)P15
      WRITE(I2,14)VB15
      WRITE(I2,15)H15
      WRITE(I2,16)S15
      WRITE(I2,10)
      WRITE(I2,17)
      WRITE(I2,18)T16
      WRITE(I2,19)P16
      WRITE(I2,20)VB16
      WRITE(I2,21)H16
      WRITE(I2,22)S16
      WRITE(I2,10)
C                       HX1 DATA
       READ(I3,69)J
       READ(I3,100)DH,TP,TS,SIG,ANREI
       READ(I3,100)ANTUI(J),C,ANH,ANC,FS
       READ(I3,100)RA,RF,BX,BY,BPR
       READ(I3,100)W1
      WRITE(I2,23)
      WRITE(I2,25)DH
      WRITE(I2,26)TP
      WRITE(I2,27)TS
      WRITE(I2,28)SIG
      WRITE(I2,29)ANREI
      WRITE(I2,30)C
      WRITE(I2,31)FS
      WRITE(I2,32)RF
      WRITE(I2,24)T17
       WRITE(I2,10)
       READ(I3,100)XI,ANPI
       SE14=1.600
       SF16=2.9225
10007  CONTINUE
```

```
C************INITIAL CONDITIONS***********
       T13I=T14+10.
       P13I=1.02*P14
       T17I=T16+10.
       P17I=0.98*P16
      CALL HX1(1,P13,V13,T13,P14,V14,T14,P16,V16,T16,P17,V17,T17,
     1 XI,ANPI,P13I,T13I,P17I,T17I,CPCM,CPHM)
       SE13=1.66+((CPHM*ALOG(T13/T14))-(1.98718*ALOG(P13/P14)))
       SE17=2.9225+((CPCM*ALOG(T17/T16))-(1.98718*ALOG(P16/P17)))
      WRITE(I2,10)
      WRITE(I2,34)
       IF(KR)900,1900,901
901    GO TO 903
900    CALL OUTPUT(1)
903    CONTINUE
       WRITE(I2,57)P13,V13,T13
       WRITE(I2,58)P17,V17,T17
       WRITE(I2,60)V14
       WRITE(I2,10)
1900   CONTINUE
       WRITE(I2,104)
       READ(I1,101) NGO
       IF(NGO)10007,10007,10008
10008  CONTINUE
C     HX2 &TURBINE DATA
       READ(I3,69)J
       READ(I3,100)DH,TP,TS,SIG,ANRE1
       READ(I3,100)C,ANH,ANC,FS
       READ(I3,100)RA,RF,BX,BY,BPR
       READ(I3,100)WT1,W2,ANT1
      WRITE(I2,73)J
      WRITE(I2,61)ANT1
      WRITE(I2,25)DH
      WRITE(I2,62)DH2
      WRITE(I2,26)TP
      WRITE(I2,27)TS
      WRITE(I2,63)SIG1
      WRITE(I2,64)SIG2
      WRITE(I2,29)ANRE1
      WRITE(I2,30)C
      WRITE(I2,31)FS
      WRITE(I2,32)RF
      WRITE(I2,66)J,W2
       JXA=J-1
       WRITE(I2,65)JXA,WT1
       WRITE(I2,10)
       READ(I3,100)XI,ANPI
10005  CONTINUE
C*********INITIAL CONDITIONS*******
       T12I=T13+5.
```

```
      P12I=1.02*P13
      T18I=T17+5.
      P18I=0.98*P17
      CALL HX2(2,P12,V12,T12,P13,V13,T13,P17,V17,T17,P18,V18,T18,
     1 XI,ANPI,P12I,T12I,P18I,T18I,CPCM,CPHM)
      SE12=SE13 +((CPHM*ALOG(T12/T13))-(1.98718*ALOG(P12/P13)))
      SE18=SE17    +((CPCM*ALOG(T18/T17))-(1.98718*ALOG(P17/P18)))
      WRITE(I2,10)
      WRITE(I2,74)J
      IF(KR)904,1904,905
905   GO TO 906
904   CALL OUTPUT(2)
906   CONTINUE
      WRITE(I2,56)P12,V12,T12
      WRITE(I2,59)P18,V18,T18
      WRITE(I2,68)V13
      WRITE(I2,10)
1904  CONTINUE
      WRITE(I2,104)
      READ(I1,101) NGO
      IF(NGO)10005,10005,10006
10006 CONTINUE
C     HX3 OATA
      REAO(I3,69)J
      READ(I3,100)OH,TP,TS,SIG,ANRE1
      REAO(I3,100)ANTUI(J),C,ANH,ANC,FS
      REAO(I3,100)RA,RF,BX,BY,BPR
      REAO(I3,100)W2
      WRITE(I2,73)J
      WRITE(I2,25)DH
      WRITE(I2,26)TP
      WRITE(I2,27)TS
      WRITE(I2,28)SIG
      WRITE(I2,29)ANRE1
      WRITE(I2,30)C
      WRITE(I2,31)FS
      WRITE(I2,32)RF
      WRITE(I2,72)ANTUI(J)
      WRITE(I2,10)
      READ(I3,100)XI,ANPI
C*********INITIAL CONDITIONS**************
      T11I=T12+75.
      P11I=1.02*P12
      T19I=T11+75.
      P19I=0.98*P18
10003 CONTINUE
      CALL HX1(3,P11,V11,T11,P12,V12,T12,P18,V18,T18,P19,V19,T19,
     1 XI,ANPI,P11I,T11I,P19I,T19I,CPCM,CPHM)
      SE11=SE12 +((CPHM*ALOG(T11/T12))-(1.98718*ALOG(P11/P12)))
      SE19=SE18    +((CPCM*ALOG(T19/T18))-(1.98718*ALOG(P18/P19)))
```

```
          WRITE(I2,10)
 73       FØRMAT(1X,3HHX-,I2,5H DATA)
 74       FØRMAT(1X,15HØUTPUT FRØM HX-,I2)
          WRITE(I2,74)J
          IF(KR)907,1907,908
 908      GØ TØ 909
 907      CALL ØUTPUT(3)
 909      CØNTINUE
          WRITE(I2,75)P11,V11,T11
          WRITE(I2,76)P19,V19,T19
          WRITE(I2,77)V12
 75       FØRMAT(1X,5H P11=F15.8,5H V11=F15.8,5H T11=F15.8)
 76       FØRMAT(1X,5H P19=F15.8,5H V19=F15.8,5H T19=F15.8)
 77       FØRMAT(1X,5H V12=F15.8)
 1907     CØNTINUE
          WRITE(I2,104)
          READ(I1,101) NGØ
          IF(NGØ)10003,10003,10004
 10004    CØNTINUE
          WRITE(I2,10)
          IF(T19-540.)504,999,999
 504      CØNTINUE
 C        HX4 DATA
          READ(I3,69)J
          READ(I3,100)DH,TP,TS,SIG,ANRE1
          READ(I3,100)C,ANH,ANC,FS
          READ(I3,100)RA,RF,BX,BY,BPR
          READ(I3,100)W2,WT2,W3,ANT1
         WRITE(I2,73)J
         WRITE(I2,61)ANT1
         WRITE(I2,25)DH
         WRITE(I2,62)DH2
         WRITE(I2,26)TP
         WRITE(I2,27)TS
         WRITE(I2,63)SIG1
         WRITE(I2,64)SIG2
         WRITE(I2,29)ANRE1
         WRITE(I2,30)C
         WRITE(I2,31)FS
         WRITE(I2,32)RF
         WRITE(I2,66)J,W2
          JXA=J-1
          WRITE(I2,65)JXA,WT1
          WRITE(I2,10)
          READ(I3,100)XI,ANPI
 10504    CØNTINUE
 C*******INITIAL CØNDITIØNS***********
          T10I=T11+10.
          P10I=1.02*P11
          T20I=T19+10.
```

```
      P20I=0.95*P19
      CALL HX2(4,P10,V10,T10,P11,V11,T11,P19,V19,T19,P20,V20,T20,
     1 XI,                  ANPI,P10I,T10I,P20I,T20I,CPCM,CPHM)
      SE10=SE11 +((CPHM*ALØG(T10/T11))-(1.98718*ALØG(P10/P11)))
      SE20=SE19   +((CPCM*ALØG(T20/T19))-(1.98718*ALØG(P19/P20)))
      WRITE(I2,10)
      WRITE(I2,74)J
      IF(KR)910,1910,911
911   GO TØ 912
910   CALL ØUTPUT(4)
912   CØNTINUE
456   FØRMAT(1X,5H P10=F15.8,5H V10=F15.8,5H T10=F15.8)
459   FØRMAT(1X,5H P20=F15.8,5H V20=F15.8,5H T20=F15.8)
468   FØRMAT(1X,5H V11=F15.8)
      WRITE(I2,456)P10,V10,T10
      WRITE(I2,459)P20,V20,T20
      WRITE(I2,468)V11
1910  CØNTINUE
      WRITE(I2,104)
      READ(I1,101) NGØ
      IF(NGØ)10504,10504,10002
10002 CØNTINUE
      WRITE(I2,10)
      IF(T20-540.)505,999,999
505   CØNTINUE
C     HX5 DATA
      READ(I3,69)J
      READ(I3,100)DH,TP,TS,SIG,ANRE1
      READ(I3,100)ANTUI(J),C,ANH,ANC,FS
      READ(I3,100)RA,RF,BX,BY,BPR
      READ(I3,100)W3
      WRITE(I2,73)J
      WRITE(I2,25)DH
      WRITE(I2,26)TP
      WRITE(I2,27)TS
      WRITE(I2,28)SIG
      WRITE(I2,29)ANRE1
      WRITE(I2,30)C
      WRITE(I2,31)FS
      WRITE(I2,32)RF
      WRITE(I2,72)ANTUI(J)
      WRITE(I2,10)
      READ(I3,100)XI,ANPI
      T9I =T10+100.
      P9I=1.02*P10
      T21I=T20+100.
      P21I=0.98*P20
10505 CØNTINUE
      CALL HX1(5,P9 ,V9 ,T9 ,P10,V10,T10,P20,V20,T20,P21,V21,T21,
     1          XI            ,ANPI,P9I,T9I ,P21I,T21I,CPCM,CPHM)
```

```
      SE9=SE10 +((CPHM*ALØG(T9/T10))-(1.98718*ALØG(P9/P10)))
      SE21=SE20   +((CPCM*ALØG(T21/T20))-(1.98718*ALØG(P20/P21)))
      WRITE(I2,10)
      WRITE(I2,74)J
      IF(KR)913,1913,914
914   GØ TØ 915
913   CALL ØUTPUT(5)
915   CØNTINUE
      WRITE(I2,575)P9,V9,T9
      WRITE(I2,576)P21,V21,T21
      WRITE(I2,577)V10
575   FØRMAT(1X,5H P9 =F15.8,5H V9 =F15.8,5H T9 =F15.8)
576   FØRMAT(1X,5H P21=F15.8,5H V21=F15.8,5H T21=F15.8)
577   FØRMAT(1X,5H V10=F15.8)
1913  CØNTINUE
      WRITE(I2,104)
      READ(I1,101) NGØ
      IF(NGØ)10505,10505,10001
10001 CØNTINUE
      WRITE(I2,10)
      IF(T21-540.)506,999,999
506   CØNTINUE
C     HX6 DATA
      READ(I3,69)J
      READ(I3,100)DH,TP,TS,SIG,ANRE1
      READ(I3,100)C,ANH,ANC,FS
      READ(I3,100)RA,RF,BX,BY,BPR
      READ(I3,100)W3,WT3,W4,ANT1
      WRITE(I2,73)J
      WRITE(I2,61)ANT1
      WRITE(I2,25)DH
      WRITE(I2,62)DH2
      WRITE(I2,26)TP
      WRITE(I2,27)TS
      WRITE(I2,63)SIG1
      WRITE(I2,64)SIG2
      WRITE(I2,29)ANRE1
      WRITE(I2,30)C
      WRITE(I2,31)FS
      WRITE(I2,32)RF
      WRITE(I2,66)J,W2
      JXA=J-1
      WRITE(I2,65)JXA,WT1
      WRITE(I2,10)
      READ(I3,100)XI,ANPI
C*********9INITIAL CØNDITIØNS************
      T8I=T9+10.
      P8I=1.02*P9
      T22I=T21+10.
      P22I=0.98*P21
```

```
      CALL HX2(6,P8 ,V8 ,T8 ,P9 ,V9 ,T9 ,P21,V21,T21,P22,V22,T22,
     1 XI,                ANPI,P8I,T8I ,P22I,T22I,CPCM,CPHM)
      SE8=SE9 +((CPHM*ALOG(T8/T9))-(1.98718*ALOG(P8/P9)))
      SE22=SE21    +((CPCM*ALOG(T22/T21))-(1.98718*ALOG(P21/P22)))
      WRITE(I2,10)
      WRITE(I2,74)J
      IF(KR)916,1916,917
917   GO TO 918
916   CALL OUTPUT(6)
918   CONTINUE
      WRITE(I2,656)P8,V8,T8
      WRITE(I2,659)P22,V22,T22
      WRITE(I2,668)V9
656   FORMAT(1X,5H P8 =F15.8,5H V8 =F15.8,5H T8 =F15.8)
659   FORMAT(1X,5H P22=F15.8,5H V22=F15.8,5H T22=F15.8)
668   FORMAT(1X,5H V9 =F15.8)
1916  CONTINUE
      WRITE(I2,10)
      IF(T22-540.IFVFFVLRM7    CONTINUE
C     HX7 DATA
      READ(I3,69)J
      READ(I3,100)DH,TP,TS,SIG,ANRE1
      READ(I3,100)ANTUI(J),C,ANM,ANC,FS
      READ(I3,100)RA,RF,BX,BY,BPR
      READ(I3,100)W4
      WRITE(I2,73)J
      WRITE(I2,25)DH
      WRITE(I2,P6)TP
      WRITE(I2,27)TS
      WRITE(I2,28)SIG
      WRITE(I2,29)ANRE1
      WRITE(I2,30)C
      WTE(I2,31)FS
      WRITE(I2,32)RF
     0WRITE(I2,72)ANTUI(J)
      WRITE(I2,10)
      READ(I3,100)XI,ANPI
C******9INITIAL CONDITIONS*************
      T7I =T8+150.
      P7I=1.02*P8
      T23I=T22+150.
      P23I=0.98*P22
      IF(KR)2005,2006,2005
2006  GO TO 1999
2005  CONTINUE
      CALL HX1(7,P7 ,V7 ,T7 ,P8 ,V8,T8 ,P22,V22,T22,P23,V23,T23,
     1          XI,          ANPI,P7I,T7I ,P23I,T23I,CPCM,CPHM)
      SE7=SE8 +((CPHM*ALOG(T7/T8))-(1.98718*ALOG(P7/P8)))
      SE23=SE22    +((CPCM*ALOG(T23/T22))-(1.98718*ALOG(P22/P23)))
```

```
      WRITE(I2,10)
      WRITE(I2,74)J
      IF(KR)919,1919,920
920   GO TO 921
919   CALL OUTPUT(7)
921   CONTINUE
      WRITE(I2,775)P7,V7,T7
      WRITE(I2,776)P23,V23,T23
      WRITE(I2,777)V8
775   FORMAT(1X,5H P7 =F15.8,5H V7 =F15.8,5H T7 =F15.8)
776   FORMAT(1X,5H P23=F15.8,5H V23=F15.8,5H T23=F15.8)
777   FORMAT(1X,5H V8 =F15.8)
1919  CONTINUE
      WRITE(I2,10)
      IF(KR)999,1999,1001
1999  SEM=AMAX1(SE7,SE8,SE9,SE10,SE11,SE12,SE13,SE14,SE15,SE16,
     1 SE17,SE18,SE19,SE20,SE21,SE22,SE23)
      TM=AMAX1(T7,T8,T9,T10,T11,T12,T13,T14,T15,T16,T17,T18,T19,
     1 T20,T21,T22,T23)
      DX=SEM/10.
      DY=540./10.
1001  READ(I1,101)  J
      CALL OUTPUT(J)
      GO TO 1001
999   STOP
      END
      END

EOF READ($MAIN$)100
+
```

```
      SUBROUTINE HX1(J,PA0,VA0,TA0,PAI,VAI,TAI,PBI,VBI,TBI,PC0,VC0,
     1 TC0,XI,ANPI,PA0I,TA0I,PC0I,TC0I,CPCM,CPHM)
C     TURBINE DESIGN PROGRAM-HELIUM
C     CRYOGENIC TURBOMACHINE SYSTEMS WITH JT VALVE----GAS AND
C     /OR VAPOR PHASE LOAD
C     VERSION 15JULY 1970
      DIMENSION S(8),AN(8),AX1(8),AH1(8),AF1(8)
      DIMENSION XPR(8),YPR(8),ANP(8),DP1(8),ANPR1(8)
      DIMENSION ANPR(8),ANNU1(8),H12(8),ANRE2(8)
      DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
      DIMENSION AK23(8),AK34(8),AK45(8),U(8)
      DIMENSION AXTHS(8),AXP(8),EI(8),ANS(8)
      DIMENSION QL(8),AE(8),WX(8),HY(8),ALL(8)
      DIMENSION CW(8),HW(8),TW(8),ANF(8),AV(8)
      DIMENSION CH1(8),CC2(8),S2(8),AN2(8),AH2(8)
      DIMENSION K1(8),K21(8),K3(8),K4(8)
      DIMENSION ANTU(8),DHT(8),AKWT(8),ANTUI(8),AKP(5),TLX(5)
      DIMENSION XPR1(8),YPR1(8),YPR2(8),YPR3(8)
      DIMENSION ALAM(8),TX(8)
      COMMON S,AN,AX1,AH1,AF1,XPR,YPR,ANP,DP1,ANPR1,ANPR
      COMMON ANNU1,H12,ANRE2,DP2,ANPR2,ANNU2,H56, AK23,AK34
      COMMON AK45,U,AXTHS,AXP,EI,ANS,QL,AE,WX,HY,ALL,CW,HW,TW
      COMMON ANF,AV,CH1,CC2,S2,AN2,AH2,K1,K21,K3,K4
      COMMON T14,P14,VB14,H14,S14,W1
      COMMON T15,P15,VB15,H15,S15
      COMMON T16,P16,VB16,H16,S16
      COMMON DH,TP,SIG,ANRE1,C,FS,RF,ANTU,TS
      COMMON ANT1,DH2,SIG1,SIG2,W2,WT1
      COMMON DHT,AKWT,ANTUI,MAT,TLX
      COMMON BX,BY,ANH,ANC
      COMMON XPR1,YPR1,YPR2,YPR3
      COMMON ALAM,TX,BPR,RA
1     FORMAT(1X,10HERROR STOP,2X,F15.8)
2     FORMAT(1X,4(F15.8,2X))
3     FORMAT(1X,27HREDUCE ANRE1 OR INCREASE RA)
4     FORMAT(1X,12HREDUCE ANTUI)
5     FORMAT(1X,11HINCREASE FS)
6     FORMAT(1X,9HREDUCE FS)
7     FORMAT(1X,15HXI IS TOO LARGE)
      I2=1
C     INITIAL VALUES
      KT1=0
      ANP(J)=ANPI
      TA0=TA0I
      PC0=PC0I
C******INITIAL X VALUE IS CALCULATED NEXT***
      X=FS*(((C-1.)*BPR)+ANH+(2.*BY))
      XI=X
      PA0=PA0I
      TC0=TC0I
```

```
      K1(J)=0
      K2=0
      K3(J)=0
      K4(J)=0
      K5=0
       K21(J)=0
       NN3=0
      N1=0
      N2=0
       N3=0
      PI=3.14159
      E=2.718282
C     HØT SIDE
C     EQ.1*
      S(J)= SQRT(0.906894*((DH**2)/SIG))
      AN(J)=(4.*SIG)/(PI*(DH**2))
      AX1(J)=(AN(J)*PI*DH*TP)+(2.*(1.-SIG))
C     EQ.4
200    ANP(J)=ANP(J)
300    TAØ=TAØ
42     PAØ=PAØ
       K1(J)=0
C     LG1
      IF(TAØ-40.)50,50,60
C     EQ.7
50    VBAØ=(2.765/E**(0.03*((PAØ**0.333333)/(TAØ/40.))))*(TAØ/PAØ)
      GØ TØ 61
C     EQ.8
60    VBAØ=2.863092*(TAØ/PAØ)
61    CØNTINUE
C      EQ.9
      UAØ=(2.37888E-07)*(TAØ**0.643)
      VAØ=(12.*ANRE1*VBAØ*UAØ)/DH
      AH1(J)=(144.*W1*VBAØ)/VAØ
      AF1(J)=AH1(J)/SIG
C     EQ.13,ASSUME X
100   X=X
      XPR(J)=X-(2.*BX)
      YPR(J)=((X/FS)-(2.*BY))
C     EQ.16
       YPR1(J)=(YPR(J)-((C-1.)*BPR)-ANH)/(2.*(C-1.))
      AF1C=ANH*(XPR(J)*YPR1(J))
      K1(J)=K1(J)+1
C     TEST1
      IF(AF1C-(AF1(J)+0.001))101,101,10101
101   IF(AF1C-(AF1(J)-0.001))10100,150,150
10101  IF(K1(J)-1)2000,10111,10102
10111  X=X/1.5
       K1(J)=0
       GØ TØ 100
```

```
10100  IF(KT1-4)10105,10104,10104
10105  IF(K1(J)-1)2000,10115,10116
10115  T1XA=X
       T1YA=AF.C
       T1ZA=AF1(J)
10116  X=1.5*X
       GO TO 100
10102  IF(KT1-4)10106,10104,10104
10106  T1XB=X
       T1YB=AF1C
       T1ZB=AF1(J)
       KT1=3
10104  CALL ITERA(T1XA,T1XB,T1YA,T1YB,T1ZA,T1ZB,T1DYA1,T1DYA2,
     1 T1DYB3,T1DYB4,T1DYI,X,AF1C,AF1(J),KT1)
       KT1=KT1+1
       GO TO 100
C      EQ.18
150    YPR2(J)=YPR1(J)*(RA/2.)
       YPR3(J)=YPR1(J)*RA
       AL1=YPR1(J)/24.
       KT1=0
       K1(J)=0
       AL2=BPR/12.
       AL3=YPR3(J)/(12.*RA)
C      HOT SIDE PRESSURE DROP
       DP1A=(VA0**2)/VBAG
       DP1P=370.0E-06*DP1A*SQRT((TP/DH)/ANRE1)
C      EQ.24
       DP1(J)=ANP(J)*DP1P
       PA0C=PA1+DP1(J)
       NN3=NN3+1
C      TEST2
474    IF(PA0C-(PA0-1.0E-03))476,477,477
477    IF(PA0C-(PA0+1.0E-03))478,478,476
476    IF(NN3-5)4761,4762,4763
4762   PA0A=PA0
       PA0CA=PA0C
       PA0ZA=PA0
       GO TO 4761
4763   IF(NN3-6)4765,4765,4766
4765   PA0B=PA0
       PA0CB=PA0C
       PA0ZB=PA0
4766   K31=NN3-3
       CALL ITERA(PA0A,PA0B,PA0CA,PA0CB,PA0ZA,PA0ZB,T3DYA1,T3DYA2,
     1 T3DYB3,T3DYB4,T3DYI,PA0,PA0C,PA0,K31)
       GO TO 42
4761   PA0 =PA0C
       GO TO 42
C      EQ.26
```

```
478     CONTINUE
        UMI=(8.55497E-04/(TA0-TAI))*(((TA0**1.643)-(TAI**1.643))/1.643)
        AKMI=(57.79E-03/(0.00355*(TA0-TAI)))*((((0.00355*TA0)**1.642)
      $ -((0.00355*TAI)**1.642))/1.642)
        THM=((AKMI/57.79E-03)**(1./.642))/0.00355
        PHM=(PA0+PAI)/2.
        NN3=0
        CALL  CPSUB(THM,PHM,CP)
350     CPHM=CP
C       EQ.29
        CHI(J)=WI*CPHM
        ANPRI(J)=(CPHM*UMI)/AKMI
        ANNUI(J)=3.66+(((0.104)/((TP/DH)/(ANREI*ANPRI(J))))/(1.+((0.016)
      1 /(((TP/DH)/(ANREI*ANPRI(J)))**0.8))))
        HI2(J)=(12.*ANNUI(J)*AKMI)/DH
C       COLD SIDE
4000    TC0=TC0
400     PC0=PC0
C       LG2
        IF(TC0-40.)441,441,442
441     VBC0=(2.765/(E**(0.03*((PC0**0.333333)/(TC0/40.)))))*(TC0/PC0)
        GO TO 443
442     VBC0=2.863092*(TC0/PC0)
443     AH2(J)=RA*AHI(J)
        VC0=(144.*WI*VBC0)/AH2(J)
C       EQ.41
        UC0=(2.37888E-07)*(TC0**0.643)
        ANRE2(J)=(VC0*DH)/(12.*VBC0*UC0)
        DPM=(VC0**2)/VBC0
        DP2P=370.0E-06*DPM*SQRT((TP/DH)/ANRE2(J))
        DP2(J)=ANP(J)*DP2P
C       EQ.45
        PC0C=PBI-DP2(J)
        K2=K2+1
C       TEST3
4862    IF(PC0C-(PC0+0.001   ))4863,4863,4861
4863    IF(PC0C-(PC0-0.001))4861,483,483
4861    IF(K2-5)4881,481,4882
481     PC0A=PC0
        T2YA=PC0C
        T2ZA=PC0
        GO TO 4881
4882    IF(K2-6)487,487,4883
487     PC0B=PC0
        T2YB=PC0C
        T2ZB=PC0
4883    KM=K2-3
        CALL  ITERA(PC0A,PC0B,T2YA,T2YB,T2ZA,T2ZB,T2DYA1,T2DYA2,
      1 T2DYB3,T2DYB4,T2DYI,PC0,PC0C,PC0,KM)
        IF(PC0 )2000,400,400
```

```
4881    PC0=PC0C
        G0 T0 400
C       EQ.46
463     CONTINUE
C       TEST4
        IF(PC0C-10.)4830,4831,4831
4830    WRITE(I2,3)
        G0 T0 9999
4831    CONTINUE
        UM2=(8.55497E-04/(TC0-TBI))*(((TC0**1.643)-(TBI**1.643))/1.643)
        AKM2=(57.79E-03/(0.00355*(TC0-TBI)))*
       $ ((((0.00355*TC0)**1.642)-((0.00352*TBI)**1.642)) /1.642)
        TCM=((AKM2/57.79E-03)**(1./.642))/0.00355
        PCM=(PBI+PC0)/2.
        K21(J)=K21(J)+K2
        K2=0
        CALL CPSUB(TCM,PCM,CP)
550     CPCM=CP
C       EQ.49
        CC2(J)=W1*CPCM
        ANPR2(J)=(CPCM*UM2)/AKM2
        ANNU2(J)=3.66+(((0.104)/((TP/DH)/(ANRE2(J)*ANPR2(J))))
       1        /(1.+((0.016) /(((TP/DH)/(ANRE2(J)*ANPR2(J)))**0.8))))
C       EQ.70
        H56(J)=(12.*ANNU2(J)*AKM2)/DH
        IF(K3(J)-5000)5570,5570,9999
5570    CONTINUE
C       LG3
        K3(J)=K3(J)+1
        IF(CH1(J)-(CC2(J)-1.0E-06))556,557,557
557     IF(CH1(J)-(CC2(J)+1.DE-06))560,56D,558
C       EQ.50
556     DEL1=(TAI-TBI)*(E**(ANTUI(J)*(1.-(CH1(J)/CC2(J)))))
        DELX=(DEL1-(TAI-TBI))/((CC2(J)/CH1(J))-1.)
        DELY=(CC2(J)/CH1(J))*DELX
        TC0C=TBI+DELX
        G0 T0 5750
C       EQ.62
560     Z=(TAI-TBI)/(1.-(ANTUI(J)/(1.+ANTUI(J))))
        TC0C=(TBI+Z)-(TAI-TBI)
        G0 T0 5750
C       EQ.56
558     DEL1=(TAI-TBI)*(E**(ANTUI(J)*(1.-(CC2(J)/CH1(J)))))
        DELX=(DEL1-(TAI-TBI))/((CH1(J)/CC2(J))-1.)
        DELY=(CH1(J)/CC2(J))*DELX
        TC0C=TBI+DELX
5750    N3=N3+1
C       TEST5
575     IF(TC0C-(TC0-1.0E-03))576,577,577
577     IF(TC0C-(TC0+1.0E-03))578,578,576
```

```
576     IF(N3-5)5761,5762,5763
5762    TC0A=TC0
        TC0CA=TC0C
        TC0ZA=TC0
        GO TO 5761
5763    IF(N3-6)5765,5765,5766
5765    TC0B=TC0
        TC0CB=TC0C
        TC0ZB=TC0
5766    K31=N3-3
        CALL ITERA(TC0A,TC0B,TC0CA,TC0CB,TC0ZA,TC0ZB,T3DYA1,T3DYA2,
     1  T3DYB3,T3DYB4,T3DYI,TC0,TC0C,TC0,K31)
        GO TO 4000
5761    TC0 =TC0C
        GO TO 4000
578     IF(CH1(J)-(CC2(J)-1.0E-06))5781,5782,5782
5782    IF(CH1(J)-(CC2(J)+1.0E-06))5783,5783,5784
5783    TA0C=TBI+Z
        GO TO 5785
5781    TA0C=TAI+DELY
        GO TO 5785
5784    TA0C=TAI+DELY
5785    N4=N4+1
        N3=0
C       TEST6
        IF(TA0C-(TA0-1.0E-03))57600,57700,57700
57700     IF(TA0C-(TA0+1.0E-03))57800,57800,57600
57600     IF(N4-5)57610,57620,57630
57620    TA0A=TA0
        TA0CA=TA0C
        TA0ZA=TA0
        GO TO 57610
57630    IF(N4-6)57650,57650,57660
57650    TA0B=TA0
        TA0CB=TA0C
        TA0ZB=TA0
57660    K41=N4-3
        CALL ITERA(TA0A,TA0B,TA0CA,TA0CB,TA0ZA,TA0ZB,T4DYA1,T4DYA2,
     1  T4DYB3,T4DYB3,T4DYI,TA0,TA0C,TA0,K41)
        GO TO 300
57610    TA0 =TA0C
        GO TO 300
57800   IF(CH1(J)-(CC2(J)-1.0E-06))5791,5790,5790
5790    IF(CH1(J)-(CC2(J)+1.0E-06))5792,5792,5793
5791    EIA=CH1(J)/CC2(J)
        EI(J)=(1.-(E**(-ANTUI(J)*(1.-EIA))))
     1  /(1.-(EIA*(E**(-ANTUI(J)*(1.-EIA)))))
        GO TO 5795
5792    EI(J)=ANTUI(J)/(1.+ANTUI(J))
        GO TO 5795
```

```
5793   EIA= CC2(J)/CH1(J)
       EI(J)=(1.-(E**(-ANTUI(J)*(1.-EIA))))
     1 /(1.-(EIA*(E**(-ANTUI(J)*(1.-EIA)))))
C      EQ.66
5795   CONTINUE
       N1=0
       N2=0
       N3=0
       N4=0
C      LG4
       TPR1=THM-((YPR1(J)/(YPR1(J)+YPR2(J)+YPR3(J)))*(THM-TCM))
       TPR2=THM-(((YPR1(J)+YPR2(J))/(YPR1(J)+YPR2(J)+YPR3(J)))*
     $ (THM-TCM))
       IF(THM     )601,602,602
602    IF(THM-TLX(MAT))666,666,604
604    IF(THM-540.)667,667,6671
601    GO TO 2011
605    GO TO 2012
C      EQ.71
666    AKP(1)=(1./(.1*(THM-TPR1)))*(((49./2.)*(((.1*THM)**2))-
     $ ((.1*TPR1)**2))-((1./3.47)*(((.1*THM)**3.47)-((.1*TPR1)**3.47
     $ ))))
C      EQ.74
       AKP(2)=(1./(THM-TPR1))*(((2.765/2.)*((THM**2)-(TPR1**2)))-
     $ (((THM**2.16)-(TPR1**2.16))/2.16))
       GO TO 668
C      EQ.73
6671   AKP(1)=111.74
C      EQ.76
       AKP(2)=92.25
       GO TO 668
C      EQ.72
667    AKP(1)=(1./(.1*(THM-TPR1)))*((-(((.1*THM)**2.708)-((.1*TPR1)
     $ **2.708))/2.708)+(.9551*(((.1*THM)**2)-((.1*TPR1)**2))))
C      EQ.75
       AKP(2)=86.+(6.25*(((THM+TPR1)/2)-210.)/330.)
C      EQ.77
668    AK23(J)=AKP(MAT)*0.93061*((S(J)-DH)/(S(J)-(DH/2.)))
C      LG8
       IF(TPR1      )660,661,661
661    IF(TPR1 -TLX(MAT))670,670,662
662    IF(TPR1 -540.)671,671,6711
660    GO TO 2013
663    GO TO 2014
C      EQ.79
670    AKP(1)=(1./(.1*(TPR1-TPR2)))*(((49./2.)*(((.1*TPR1)**2))-
     $ ((.1*TPR2)**2))-((1./3.47)*(((.1*TPR1)**3.47)-((.1*TPR2)**3.47
     $ ))))
C      EQ82
       AKP(2)=(1./(TPR1-TPR2))*(((2.765/2.)*((TPR1**2)-(TPR2**2)))-
```

```
     $ (((TPR1**2.16)-(TPR2**2.16))/2.16))
       GO TO 672
C      EQ.81
6711   AKP(1)=111.74
C      EQ.84
       AKP(2)=92.25
       GO TO 672
C      EQ.80
671    AKP(1)=(1./(.1*(TPR1-TPR2)))*((-(((.1*TPR1)**2.708)-((.1*TPR2)
     $ **2.708))/2.708)+(.9551*(((.1*TPR1)**2)-((.1*TPR2)**2))))
C      EQ.83
       AKP(2)=86.+(6.25*(((TPR1+TPR2)/2)-210.)/330.)
C      EQ.85
672    AK34(J)=AKP(MAT)
C      LGIO
       IF(TPR2    )673,674,674
674    IF(TPR2-TLX(MAT))675,675,676
676    IF(TPR2-540.)677,677,6771
673    GO TO 2015
678    GO TO 2016
C      EQ.86
675    AKP(1)=(1./(.1*(TPR2-TCM  )))*(((49./2.)*(((.1*TPR2)**2))-
     $ ((.1*TCM  )**2))-((1./3.47)*(((.1*TPR2)**3.47)-((.1*TCM  )**3.47
     $ ))))
C      EQ.89
       AKP(2)=(1./(TPR2-TCM  ))*(((2.765/2.)*((TPR2**2)-(TCM  **2)))-
     $ (((TPR2**2.16)-(TCM  **2.16))/2.16))
       GO TO 679
C      EQ.88
6771   AKP(1)=111.74
C      EQ.91
       AKP(2)=92.25
       GO TO 679
C      EQ.87
677    AKP(1)=(1./(.1*(TPR2-TCM  )))*((-(((.1*TPR2)**2.708)-((.1*TCM  )
     $ **2.708))/2.708)+(.9551*(((.1*TPR2)**2)-((.1*TCM  )**2))))
C      EQ.90
       AKP(2)=86.+(6.25*(((TPR2+TCM  )/2)-210.)/330.)
       AKP(2)=86.+(6.25*((TCM-210.)/330.))
C      EQ.92
679    AK45(J)=AKP(MAT)*0.93061*((S(J)-DH)/(S(J)-(DH/2.)))
C      EQ.93
       U(J)=1./((1./H12(J))+(AL1/AK23(J))+(AL2/AK34(J))+(AL3/AK45(J))
     1    +(1./H56(J)))
C      EQ.94
708    ANS(J)=ANP(J)+1.
       N2=0
       ALE=(ANS(J)*TS)/12.
       TL1=(TAI+TBI)/2.
       TL2=(TA0+TC0)/2.
```

```
      Y=X/FS
      AKL=(((X+Y)-(XPR(J)*YPR(J)))+((C-1.)*XPR(J)*BPR))/144.
      BA=1./(TL2-TL1)
      AKBL=(7.27E-03)*BA*(((TL2/1.585)**1.585)-((TL1/1.585)**1.585))
C     EQ.100
      QL(J)=(AKBL*AKL)/ALE
C     LG1.
      IF(CHI(J)-(CC2(J)-1.0E-06))901,902,902
902   IF(CHI(J)-(CC2(J)+1.0E-06))903,903,904
C     EQ.101
901   ALAM(J)=QL(J)/(3600.*CHI(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C     TEST7A
      IF(AE(J)-1.)9040,9041,9041
9041  WRITE(12,4)
      GØ TØ 9999
9040  CØNTINUE
      ANTU(J)=(ALØG((1.-(AE(J)*(CHI(J)/CC2(J))))/(1.-AE(J)))/
     1 (1.-(CHI(J)/CC2(J))))
      GØ TØ 7020
C     EQ.107
903   ALAM(J)=QL(J)/(3600.*CHI(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C     TEST7C
      IF(AE(J)-1.)9042,9043,9043
9043  WRITE(12,4)
      GØ TØ 9999
9042  CØNTINUE
      ANTU(J)=AE(J)/(1.-AE(J))
      GØ TØ 7020
904   ALAM(J)=QL(J)/(3600.*CC2(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C     TEST7B
      IF(AE(J)-1.)9045,9044,9044
9044  WRITE(12,4)
      GØ TØ 9999
9045  CØNTINUE
      ANTU(J)=(ALØG((1.-(AE(J)*(CC2(J)/CHI(J))))/(1.-AE(J)))/
     1 (1.-(CC2(J)/CHI(J))))
C     LG14
7020  K4(J)=K4(J)+1
      IF(CHI(J)-(CC2(J)-1.0E-06))701,702,702
702   IF(CHI(J)-(CC2(J)+1.0E-06))703,703,704
C     EQ.110
701   AXTHS(J)=(3600.*ANTU(J)*CHI(J))/U(J)
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINT(ANPC)
      IF((ANPC-ANPC1)-0.5)7011,7012,7012
7012  ANPC=ANPC1+1.
```

```
      GO TO 7013
7011  ANPC=ANPC1+1.
7013  CONTINUE
      GO TO 705
C     EQ.116
703   AXTHS(J)=(3600.*ANTU(J)*CH1(J))/U(J)
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINT(ANPC)
      IF((ANPC-ANPC1)-0.5)7031,7032,7032
7032  ANPC=ANPC1+1.
      GO TO 7033
7031  ANPC=ANPC1+1.
7033  CONTINUE
      GO TO 705
C     EQ.113
704   AXTHS(J)=(3600.*ANTU(J)*CC2(J))/U(J)
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINT(ANPC)
     IF((ANPC-ANPC1)-0.5)7041,7042,7042
7042  ANPC=ANPC1+1.
      GO TO 7043
7041  ANPC=ANPC1+1.
7043  CONTINUE
C     TEST5
705   K5=K5+1
      IF(ANPC-ANP(J))706,707,707
707   IF(ANPC-(ANP(J)+1.))1000,1000,706
706   ANP(J)=ANPC
      GO TO 200
C     SIZE & WEIGHT
C     EQ.119
1000  WX(J)=X
      HY(J)=X/FS
      ALL(J)=((ANP(J)*TP)+(ANS(J)*TS))
      XYZ=(X*Y)-(XPR(J)*YPR(J))
      XYB=XPR(J)*BPR*(C-1.)
      XYA=AF1(J)*(RA+1.)*(1.-SIG)
      XYT1=XYZ+XYB+XYA
      XYT2=XYZ+XYB
      CW(J)=(0.098*ANP(J)*TP*XYT1)+(0.078*ANS(J)*TS*XYT2)
      HW(J)=0.196*((X*Y)-(AF1(J)*(RA+1.))+(X*Y/8.))
      TW(J)=CW(J)+HW(J)
      ANF1=YPR1(J)**2
      ANF2= AXP(J)/(ANH*YPR1(J))
      ANF3=H12(J)*ANF2*ANF1
      ANF4=(S(J)-DH)/(S(J)-(DH/2.))
      ANF5=XPR(J)*TP*0.93061*ANF4
      ANF6=3.*ANP(J)*AK23(J)*ANF5
```

```
      ANF7=ANF3/ANF6
C     EQ.125
      ANF(J)=1./(1.+ANF7)
      IF(ANF(J)-.4)1970,1971,1971
1971  IF(ANF(J)-.6)1972,1972,1973
1970  WRITE(I2,5)
      GO TO 1972
1973  WRITE(I2,6)
1972  CONTINUE
      AV(J)=AXTHS(J)/((WX(J)*HY(J)*ALL(J))/1728.)
      GO TO 9999
2000  WRITE(I2,1)THM
2001  WRITE(I2,1)PHM
2002  WRITE(I2,1)PHM
2003  WRITE(I2,1)THM
2007  WRITE(I2,1)TCM
2008  WRITE(I2,1)TCM
2009  WRITE(I2,1)PCM
2010  WRITE(I2,1)PCM
2011  WRITE(I2,1)THM
2012  WRITE(I2,1)THM
2013  WRITE(I2,1)TX(J)
2014  WRITE(I2,1)TX(J)
2015  WRITE(I2,1)TCM
2016  WRITE(I2,1)TCM
9999  CONTINUE
      RETURN
      STOP
      END
      END
```

```
      SUBROUTINE HX2(J,PA0,VA0,TA0,PAI,VAI,TAI,PBI,VBI,TBI,PB0,
     1 VB0,TB0,XI,ANPI,PA0I,TA0I,PB0I,TB0I,CPCM,CPHM)
C     TURBINE DESIGN PROGRAM-HELIUM
C     CRYOGENIC TURBOMACHINE SYSTEMS WITH JT VALVE----GAS AND
C     /OR VAPOR PHASE LOAD
C     VERSION 16JULY 1970
       DIMENSION S(8),AN(8),AX1(8),AH1(8),AF1(8)
       DIMENSION XPR(8),YPR(8),ANP(8),DP1(8),ANPR1(8)
       DIMENSION ANPR(8),ANNU1(8),H12(8),ANRE2(8)
       DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
       DIMENSION AK23(8),AK34(8),AK45(8),U(8)
       DIMENSION AXTHS(8),AXP(8),EI(8),ANS(8)
       DIMENSION OL(8),AE(8),WX(8),HY(8),ALL(8)
       DIMENSION CW(8),HW(8),TW(8),ANF(8),AV(8)
       DIMENSION CH1(8),CC2(8),S2(8),AN2(8),AH2(8)
       DIMENSION K1(8),K21(8),K3(8),K4(8)
       DIMENSION ANTU(8),DHT(8),AKWT(8),ANTUI(8),AKP(5),TLX(5)
       DIMENSION XPR1(8),YPR1(8),YPR2(8),YPR3(8)
       DIMENSION ALAM(8),TX(8)
       COMMON S,AN,AX1,AH1,AF1,XPR,YPR,ANP,DP1,ANPR1,ANPR
       COMMON ANNU1,H12,ANRE2,DP2,ANPR2,ANNU2,H56, AK23,AK34
       COMMON AK45,U,AXTHS,AXP,EI,ANS,OL,AE,WX,HY,ALL,CW,HW,TW
       COMMON ANF,AV,CH1,CC2,S2,AN2,AH2,K1,K21,K3,K4
       COMMON T14,P14,VB14,H14,S14,W1
       COMMON T15,P15,VB15,H15,S15
       COMMON T16,P16,VB16,H16,S16
       COMMON DH,TP,SIG,ANRE1,C,FS,RF,ANTU,TS
       COMMON ANT1,DH2,SIG1,SIG2,W2,WT1
       COMMON DHT,AKWT,ANTUI,MAT,TLX
       COMMON BX,BY,ANH,ANC
       COMMON XPR1,YPR1,YPR2,YPR3
       COMMON ALAM,TX,BPR,RA
1     FORMAT(1X,10HERROR STOP,2X,F15.8)
2      FORMAT(1X,4(F15.8,2X))
3      FORMAT(1X,11HINCREASE RA)
4      FORMAT(1X,39HREDUCE BORDER DIMENSIONS OR INCREASE TS)
5      FORMAT(1X,11HINCREASE FS)
6      FORMAT(1X,9HREDUCE FS)
7      FORMAT(1X,15HXI IS TOO LARGE)
      I2=1
C     INITIAL VALUES
       KT1=0
C******INITIAL  VALUE OF X IS CALCULATED NEXT***
       X=FS*(((C-1.)*BPR)+ANH+(2*BY))
       XI=X
       PB0=PB0I
       TB0=TB0I
       TA0=TA0I
       ANP(J)=ANPI
       K1(J)=0
```

```
      K2=0
      K3(J)=0
      K4(J)=0
      K5=0
       K21(J)=0
       K31=0
      N1=0
      N2=0
       N3=0
       N4=0
       NN3=0
      PI=3.14159
      E=2.718282
C     HØT SIDE
C     EQ.1*
      S(J)= SQRT(0.906694*((DH**2)/SIG))
      AN(J)=(4.*SIG)/(PI*(DH**2))
      AX1(J)=(AN(J)*PI*DH*TP)+(2.*(1.-SIG))
C     EQ.4
200    ANP(J)=ANP(J)
3000   TA0=TA0
42     PA0=PA0
       K1(J)=0
C     LG1
      IF(TA0-40.)50,50,60
C     EQ.7
50    VBA0=(2.765/E**(0.03*((PA0**0.333333)/(TA0/40.))))*(TA0/PA0)
      GØ TØ 61
C     EQ.8
60    VBA0=2.863092*(TA0/PA0)
61    CØNTINUE
C      EQ.9
      UA0=(2.37888E-07)*(TA0**0.643)
      VA0=(12.*ANRE1*VBA0*UA0)/DH
      AH1(J)=(134.*W1*VBA0)/VA0
      AF1(J)=AH1(J)/SIG
C     EQ.13,ASSUME X
100   X=X
      XPR(J)=X-(2.*BX)
      YPR(J)=(X/FS)-(2.*BY)
C     EQ.16
       YPR1(J)=(YPR(J)-((C-1.)*BPR)-ANH)/(2.*(C-1.))
      AF1C=ANH*(XPR(J)*YPR1(J))
      K1(J)=K1(J)+1
C     TEST1
      IF(AF1C-(AF1(J)+0.001))101,101,10101
101   IF(AF1C-(AF1(J)-0.001))10100,150,150
10101  IF(K1(J)-1)2000,10111,10102
10111  X=X/1.5
       K1(J)=0
```

```
      G0 T0 100
10100 IF(KT1-4)10105,10104,10104
10105 IF(K1(J)-1)2000,10115,10116
10115 T1XA=X
      T1YA=AF1C
      T1ZA=AF1(J)
10116 X=1.5*X
      G0 T0 100
10102 IF(KT1-4)10106,10104,10104
10106 T1XB=X
      T1YB=AF1C
      T1ZB=AF1(J)
      KT1=3
10104 CALL ITERA(T1XA,T1XB,T1YA,T1YB,T1ZA,T1ZB,T1DYA1,T1DYA2,
     1 T1DYB3,T1DYB4,T1DYI,X,AF1C,AF1(J),KT1)
      KT1=KT1+1
      G0 T0 100
C     EQ.18
150   YPR2(J)=YPR1(J)*(RA/2.)
      YPR3(J)=YPR1(J)*RA
      AL1=YPR1(J)/24.
      KT1=0
      K1(J)=1
      AL2=BPR/12.
      AL3=YPR3(J)/(12.*RA)
C     H0T SIDE PRESSURE DR0P
      DP1A=(VA0**2)/VBA0
      DP1P=370.0E-06*DP1A*SQRT((TP/DH)/ANRE1)
      DP1(J)=ANP(J)*DP1P
C     EQ.25
      PA0C=PAI+DP1(J)
C     GET CH1
C     TEST2
474   IF(PA0C-(PA0-1.0E-03))476,477,477
477   IF(PA0C-(PA0+1.0E-03))478,478,476
476   IF(NN3-5)4761,4762,4763
4762  PA0A=PA0
      PA0CA=PA0C
      PA0ZA=PA0
      G0 T0 4761
4763  IF(NN3-6)4765,4765,4766
4765  PA0B=PA0
      PA0CB=PA0C
      PA0ZB=PA0
4766  K31=NN3-3
      CALL ITERA(PA0A,PA0B,PA0CA,PA0CB,PA0ZA,PA0ZB,T3DYA1,T3DYA2,
     1 T3DYB3,T3DYB4,T3DYI,PA0,PA0C,PA0,K31)
      G0 T0 42
4761  PA0 =PA0C
      G0 T0 42
```

```
478     CALL CPSUB(TA0,PA0,CP)
C       EQ.26
3500    CP12=CP
        CALL CPSUB(TBI,PBI,CP)
7500    CP17=CP
        NN3=0
        CPB=(CP12+CP17)/2.
       GAMB=1./(1.-(.496447467/CPB))
C       EQ.30
       T17T12=1.-ANTI*(1.-(PBI/PA0)**((GAMB-1.)/GAMB))
       TA0C=TBI/(T17T12)
C      TEST3
       K2=K2+1
2862    IF(TA0C-(TA0+0.001   ))2863,2863,2861
2863    IF(TA0C-(TA0-0.001))2861,283,283
2861    IF(K2-2)2881,281,2882
281     TA0A=TA0
        T2YA=TA0C
        T2ZA=TA0
        GO TO 2881
2882    IF(K2-6)287,287,2883
287     TA0B=TA0
        T2YB=TA0C
        T2ZB=TA0
2883    KM=K2-3
        CALL ITERA(TA0A,TA0B,T2YA,T2YB,T2ZA,T2ZB,T20YA1,T20YA2,
      1 T20YB3,T20YB4,T2DYI,TA0,TA0C,TA0,KM)
        IF(TA0 )2000,3000,3000
2881    TA0=TA0C
        GO TO 3000
C       EQ.32
283     CONTINUE
        UMI=(8.55497E-04/(TA0-TAI))*(((TA0**1.643)-(TAI**1.643))/1.643)
        AKMI=((57.79E-03)/(.00355*(TA0-TAI)))*((((.00355*TA0)**1.642)
      1 -((.00355*TAI)**1.642))/1.642)
        THM=(AKMI/57.79E-03)**1./.642)/.00355
        PHM=(PA0+PAI)/2.
        K2=0
        CALL CPSUB(THM,PHM,CP)
350     CPHM=CP
C       EQ.35
        CHI(J)=WI*CPHM
        ANPRI(J)=(CPHM*UMI)/AKMI
        ANNUI(J)=3.66+(((0.104)/((TP/DH)/(ANREI*ANPRI(J))))/(1.+((0.016)
      1 /(((TP/DH)/(ANREI*ANPRI(J)))**0.8))))
        HI2(J)=(12.*ANNUI(J)*AKMI)/DH
C       COLD SIDE
C       EQ.41
4000    TB0=TB0
C       EQ.42
```

```
400     PBO=PBO
C       LG2
        IF(TBO-40.)441,441,442
441     VBBO=(2.765/(E**(0.03*((PBO**0.333333)/(TBO/40.)))))*(TBO/PBO)
        GO TO 443
442     VBBO=2.863092*(TBO/PBO)
443     UBO=(2    .88E-07)*(TBO**0.643)
        AH2(J)=AH1(J)*RA
        VBO=(144.*W2*VBBO)/AH2(J)
        ANRE2(J)=(VBO*DH )/(12.*VBBO*UBO)
        DPM=(VBO**2)/VBBO
        DP2P=370.0E-06*DPM*SQRT((TP/DH )/ANRE2(J))
        DP2(J)=ANP(J)*DP2P
        PBOC=PBI-DP2(J)
        K32=K32+1
C       TEST4
4862    IF(PBOC-(PBO+0.001   ))4863,4863,4861
4863    IF(PBOC-(PBO-0.001))4861,483,483
4861    IF(K32-2)4881,481,4882
481     PBOA=PBO
        PBOYA=PBOC
        PBOZA=PBO
        GO TO 4881
4882    IF(K32-6)487,487,4883
487     PBOB=PBO
        PBOYB=PBOC
        PBOZB=PBO
4883    KM1=K32-3
        CALL ITERA(PBOA,PBOB,PBOYA,PBOYB,PBOZA,PBOZB,PBODYA1,PBODYA2,
     1  PBODYB3,PBODYB4,PBODYI,PBO,PBOC,PBO,KM1)
        IF(PBO )2000,400,400
4881    PBO=PBOC
        GO TO 400
C       EQ.52
C       TEST5
483     IF(PBOC-10.)4831,4832,4832
4831    WRITE(I2,3)
        GO TO 9999
4832    CONTINUE
        UM2=((8.55497E-04)/(TBO-TBI))*(((TBO**1.643)-(TBI**1.643))/1.643
        AKM2=((57.79E-03)/(.00355*(TBO-TBI)))*((((.00355*TBO)**1.642)-
     1  ((.00355*TBI)**1.642))/1.642)
        TCM=((AKM2/57.79E-03)**1./.642)/.00355
        PCM=(PBI+PBO)/2.
        K31=K31+K32
        K32=0
        CALL CPSUB(TCM,PCM,CP)
550     CPCM=CP
C       EQ.54
        CC2(J)=W2*CPCM
```

```
      IF(K4(J)-5000)5570,5570,9999
5570  CONTINUE
      ANPR2(J)=(CPCM*UM2)/AKM2
      ANNU2(J)=3.66+(((0.104)/((TP/DH)/(ANRE2(J)*ANPR2(J))))
     1     /(1.+((0.016) /(((TP/DH)/(ANRE2(J)*ANPR2(J)))**0.8))))
      H2(J)=(12.*ANNU2(J)*AKM2)/DH
C     L63
      K4(J)=K4(J)+1
      IF(CH1(J)-(CC2(J)-1.0E-06))556,557,557
557   IF(CH1(J)-(CC2(J)+1.0E-06))560,560,558
C     EQ.56
556   TB0C=TBI+(( TA0-TAI)/(CC2(J)/CH1(J)))
      GO TO 5750
C     EQ.62
560   TB0C=TA0-(TAI-TBI)
      GO TO 5750
C     EQ.59
558   TB0C=TBI+ ((TA0-TAI)/(CH1(J)/CC2(J)))
5750  N4=N4+1
C     TEST6
575   IF(TB0C-(TB0-1.0E-03))576,577,577
577   IF(TB0C-(TB0+1.0E-03))578,578,576
576   IF(N4-5)5761,5762,5763
5762  TB0A=TB0
      TB0CA=TB0C
      TB0ZA=TB0

      GO TO 5761
5763  IF(N4-6)5765,5765,5766
5765  TB0B=TB0
      TB0CB=TB0C
      TB0ZB=TB0
5766  K41=N4-3
      CALL ITERA(TB0A,TB0B,TB0CA,TB0CB,TB0ZA,TB0ZB,T3DYA1,T3DYA2,
     1 T3DYB3,T3DYB4,T3DYI,TB0,TB0C,TB0,K41)
      GO TO 4000
5761  TB0 =TB0C
      GO TO 4000
578   IF(CH1(J)-(CC2(J)-1.0E-06))5781,5782,5782
5782  IF(CH1(J)-(CC2(J)+1.0E-06))5783,5783,5784
C     EQ.63
5783  ANTUI(J)=((TA0-TAI)/(TA0-TBI))/(1.-((TA0-TAI)/(TA0-TBI)))
      EI(J)=ANTUI(J)/(1.+ANTUI(J))
      GO TO 5785
C     EQ.57
5781  ANTUI(J)=ALOG((TA0-TB0)/(TAI-TBI))/(1.-(CH1(J)/CC2(J)))
      EIA=CH1(J)/CC2(J)
      EI(J)=(1.-(E**(-ANTUI(J)*(1.-EIA))))
     1 /(1.-(EIA*(E**(-ANTUI(J)*(1.-EIA)))))
      GO TO 5785
```

```
C       FO.60
5784    ANTUI(J)=ALOG((TA0-TB0)/(TAI-TB1))/(1.-(CC2(J)/CH1(J)))
        E1A=CC2(J)/CH1(J)
        EI(J)=(1.-(E**(-ANTU(J)*(1.-E1A))))
     1   /(1.-(E1A*(E**(-ANTU(J)*(1.-EIA)))))
C       EQ.65
5785    CONTINUE
        N1=0
        N2=0
        N3=0
        N4=0
        T1PR=THM- ((YPR1(J)/(YPR1(J)+YPR2(J)+YPR3(J)))*(THM-TCM))
        T2PR=THM- (((YPR1(J)+YPR2(J))/(YPR1(J)+YPR2(J)+YPR3(J)))*
     1  (THM-TCM))
C       GET PLATE THERMAL CONDUCTIVITIES
C       LG4
        IF(THM      )601,602,602
602     IF(THM-TLX(MAT))666,666,604
604     IF(THM-540.)667,667,6671
601     GO TO 2011
605     GO TO 2012
C       EQ.70
666     AKP(1)=(1./(1.*(THM-T1PR)))*(((49./2.)*(((.1*THM)**2)-
     1  ((.1*T1PR)**2)))-((1./3.47)*(((.1*THM)**3.47)-((.1*T1PR)**3.47
     2  ))))
C       EQ.73
        AKP(2)=(1./(THM-T1PR))*(((2.765/2.)*((THM**2)-((T1PR)**2
     1  )))-(((THM**2.16)-(T1PR**2.16))/2.16))
        GO TO 668
C       EQ.72
6671    AKP(1)=111.74
C       EQ.75
        AKP(2)=92.25
        GO TO 668
C       EQ.71
667     AKP(1)=(1./(1.*(THM-T1PR)))*(- ((((.1*THM)**2.708)-
     1  ((.1*T1PR)**2.708))/2.708)+(9.551*(((.1*THM)**2)-((.1*
     2  T1PR)**2))))
C       EQ.74
        AKP(2)=86.+(6.25*((((THM+T1PR)/2.)-210.)/330.))
C       EQ.76
668     AK23(J)=AKP(MAT)*0.93061*((S(J)-DH)/(S(J)-(DH/2.)))
        TX(J)=(THM+TCM)/2.
C       LG7
        IF(TX(J)      )660,661,661
661     IF(TX(J)-TLX(MAT))670,670,662
662     IF(TX(J)-540.)671,671,6711
660     GO TO 2013
663     GO TO 2014
C       EQ.78
```

```
670     AKP(1)=(1./(1.*(T1PR-T2PR)))*(((49./2.)*(((.1*T1PR)**2)-
      1 ((.1*T2PR)**2)))-((1./3.47)*(((.1*T1PR)**3.47)-((.1*T2PR)**2.47
      2 ))))
C       E0.81
                AKP(2)=(1./(T1PR-T2PR))*(((2.765/2.)*((T1PR**2)-((T2PR)*8
      1 )))-(((T1PR**2.16)-(T2PR**2.16))/2.16))
        G0 TO 672
C       E0.80
6711    AKP(1)=111.74
C       E0.53
        AKP(2)=92.25
        G0 T0 672
C       E0.79
671     AKP(1)=(1./(1.*(T1PR-T2PR)))*(- ((((.1*T1PR)**2.708)-
      1 ((.1*T2PR)**2.708))/2.708)+(9.551*(((.1*T1PR)**2)-((.1*
      2 T2PR)**2))))
C       E0.82
        AKP(2)=86.+(6.25*((((T1PR+T2PR)/2.)-210.)/330.))
C       E0.84
672     AK34(J)=AKP(MAT)
C       LG10
        IF(TCM     )673,674,674
674     IF(TCM-TLX(MAT))675,675,676
676     IF(TCM-540.)677,677,6771
673     G0 T0 2015
678     G0 T0 2016
C       E0.85
675     AKP(1)=(1./(1.*(T2PR-TCM)))*(((49./2.)*(((.1*T2PR)**2)-
      1 ((.1*TCM)**2)))-((1./3.47)*(((.1*T2PR)**3.47)-((.1*TCM)**3.47
      2 ))))
C       E0.88
        AKP(2)=(1./(T2PR-TCM))*(((2.765/2.)*((T2PR**2)-((TCM)**2
      1 )))-(((T2PR**2.16)-(TCM**2.16))/2.16))
        G0 T0 679
C       E0.87
6771    AKP(1)=111.74
C       E0.90
        AKP(2)=92.25
        G0 T0 679
C       E0.86
677     AKP(1)=(1./(1.*(T2PR-TCM)))*(- ((((.1*T2PR)**2.708)-
      1 ((.1*TCM)**2.708))/2.708)+(9.551*(((.1*T2PR)**2)-((.1*
      2 TCM)**2))))
C       E0.89
        AKP(2)=86.+(6.25*((((T2PR+TCM )/2.)-210.)/330.))
C       E0.91
679     AK45(J)=AKP(MAT)*0.93061*((S(J)-DH )/(S(J)-(DH /2.)))
C       E0.92
        U(J)=1./(((1./H12(J))+(AL1/AK23(J))+(AL2/AK34(J))+(AL3/AK45(J))
      1     +(1./H56(J)))
```

```
C         GET ENDWISE HEAT LEAKAGE
C         EQ.93
          ANS(J)=ANP(J)+1.
          N2=0
          ALE=(ANS(J)*TS)/12.
          TL1=(TAI+TBI)/2.
          TL2=(TAO+TBO)/2.
          AKL=(((X*(X/FS))-(XPR(J)*YPR(J)))+((C-1.)*XPR(J)*BPR))/144.
          BA=1./(TL2-TL1)
          AKBL=(7.27E-03)*BA*((((TL2)**1.585)-((TL1)**1.585))/1.585)
C         EQ.99
          QL(J)=(AKBL*AKL)/ALE
C         LG13
          IF(CH1(J)-(CC2(J)-1.0E-06))901,902,902
902       IF(CH1(J)-(CC2(J)+1.0E-06))903,903,904
C         EQ.100
901       ALAM(J)=QL(J)/(3600.*CH1(J))
          AE(J)=EI(J)/(1.-ALAM(J))
C         TEST 7A
          IF(AE(J)-1.)9001,9002,9002
9002      WRITE(I2,4)
          GØ TØ 9999
9001      CØNTINUE
          ANTU(J)=(ALØG((1.-(AE(J)*(CH1(J)/CC2(J))))/(1.-AE(J)))/
         1(1.-(CH1(J)/CC2(J))))
          GØ TØ 70200
C         EQ.106
903       ALAM(J)=QL(J)/(3600.*CH1(J))
          AE(J)=EI(J)/(1.-ALAM(J))
C         TEST7C
          IF(AE(J)-1.0)9003,9002,9002
9003      CØNTINUE
          ANTU(J)=AE(J)/(1.-AE(J))
          GØ TØ 70200
C         EQ.103
904       ALAM(J)=QL(J)/(3600.*CC2(J))
          AE(J)=EI(J)/(1.-ALAM(J))
C         TEST7B
          IF(AE(J)-1.)9004,9002,9002
9004      CØNTINUE
          ANTU(J)=(ALØG((1.-(AE(J)*(CC2(J)/CH1(J))))/(1.-AE(J)))/
         1(1.-(CC2(J)/CH1(J))))
C         LG14
70200     K5(J)=K5(J)+1
          IF(CH1(J)-(CC2(J)-1.0E-06))701,702,702
702       IF(CH1(J)-(CC2(J)+1.0E-06))703,703,704
C         EQ.109
701       AXTHS(J)=((ANTU(J)*CH1(J))/U(J))*3600.
          AXP(J)=AX1(J)*AF1(J)
          ANPC=(144.*AXTHS(J))/AXP(J)
```

```
      ANPC1=AINT(ANPC)
      IF((ANPC-ANPC1)-0.5)7011,7012,7012
7012  ANPC=ANPC1+1.
      GO TO 7013
7011  ANPC=ANPC1+1.
7013  CONTINUE
      GO TO 705
C     EQ.115
703   AXTHS(J)=((ANTU(J)*CH1(J))/U(J))*3600.
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINT(ANPC)
      IF((ANPC-ANPC1)-0.5)7031,7032,7032
7032  ANPC=ANPC1+1.
      GO TO 7033
7031  ANPC=ANPC1+1.
7033  CONTINUE
      GO TO 705
C     EQ.112
704   AXTHS(J)=((ANTU(J)*CC2(J))/U(J))*3600.
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINT(ANPC)
      IF((ANPC-ANPC1)-0.5)7041,7042,7042
7042  ANPC=ANPC1+1.
      GO TO 7043
7041  ANPC=ANPC1+1.
7043  CONTINUE
C     TEST8
705   IF(ANPC-ANP(J))706,707,707
707   IF(ANPC-(ANP(J)+1.))1000,1000,706
706   ANP(J)=ANPC
      GO TO 200
C     SIZE & WEIGHT
C     EQ.113
1000  WX(J)=X
      HY(J)=X/FS
      ALL(J)=((ANP(J)*TP)+(ANS(J)*TS))
      XYZ=(X*(X/FS))-(XPR(J)*YPR(J))
      XYB=XPR(J)*BPR*(C-1.)
      XYA=AF1(J)*(RA+1.)*(1.-SIG)
      CW(J)=(0.096*ANP(J)*TP*(XYZ+XYB+XYA))+(0.073*ANS(J)*TS*(XYZ+XYB)
      HW(J)=0.196*((X*HY(J))-((RA+1.) *AF1(J))+((X*HY(J))/8.))
      TW(J)=CW(J)+HW(J)
      ANF1=YPR1(J)**2
      ANF2= AXP(J)/(ANH*YPR1(J))
      ANF3=H12(J)*ANF2*ANF1
      ANF4=(S(J)-DH)/(S(J)-(DH/2.))
      ANF5=XPR(J)*TP*0.93061*ANF4
      ANF6=3.*ANP(J)*AK23(J)*ANF5
```

```
          ANF7=ANF3/ANF6
         ANF(J)= 1./(1.+ANF7)
C         TEST9
          IF(ANF(J)-.4)7001,7002,7002
7002      IF(ANF(J)-.6)7003,7003,7004
7001      WRITE(I2,5)
          GØ TØ 7003
7004      WRITE(I2,6)
7003      CØNTINUE
          AV(J)=AXTHS(J)/((WX(J)*HY(J)*ALL(J))/1728.)
C         TURBINE 1 ØUTPUT
          DHT(J)=CPB*TAØ*ANT1*(1.-((PBI/PAØ)**((GAMB-1.)/GAMB)))
          GØ TØ 9999
2000     WRITE(I2,1)THM
2001     WRITE(I2,1)PHM
2002     WRITE(I2,1)PHM
2003     WRITE(I2,1)THM
2007     WRITE(I2,1)TCM
2008     WRITE(I2,1)TCM
2009     WRITE(I2,1)PCM
2010     WRITE(I2,1)PCM
2011     WRITE(I2,1)THM
2012     WRITE(I2,1)THM
2013     WRITE(I2,1)TX(J)
2014     WRITE(I2,1)TX(J)
2015     WRITE(I2,1)TCM
2016     WRITE(I2,1)TCM
9999      CONTINUE
          RETURN
          STØP
          END
          END
```

```
      SUBROUTINE ITERA(XA,XB,YA,YB,ZA,ZB,DYA1,DYA2,DYB3,DYB4,DYI,XI,YI,
     &ZI,N)
C
C PRØ RAM REQUIRES INPUTS(FROM MAIN) --XA,XB,YA,YB,ZA,ZB,YI,ZI
C AND ØUTPUTS(TØ MAIN)--XI
      IF(N-4)10,20,100
10    CALL ITER1(XA,XB,YA,YB,ZA,ZB,XI,DYA1,DYA2,DYB3,DYB4)
      N=N+1
      RETURN
2D    CALL ITER2(XA,XB,YA,YB,ZA,ZB,XI,DYI,DYA1,DYA2,DYB3,DYB4,YI,ZI,N)
      N=N+1
      RETURN
1OD   CØNTINUE
      CALL ITER3(XA,XB,YA,YB,ZA,ZB,XI,DYI,DYA1,DYA2,DYB3,DYB4,YI,ZI,N)
      N=N+1
      RETURN
      END
      END
      SUBRØUTINE ITER1(XA,XB,YA,YB,ZA,ZB,XI,DYA1,DYA2,DYB3,DYB4)
      DYA1=ZA-YA
      DYA2=YA-ZA
      DYB3=ZB-YB
      DYB4=YB-ZB
C     WRITE(D,2)DYA1,DYA2,DYB3,DYB4
2     FØRMAT(1X,4F15.7)
      IF(YA-ZA)99,99,1DD
99    XI=XA+((DYA1/(DYA1+DYB4))*(XB-XA))
C     WRITE(D,2)XI
      RETURN
1DD   XI=XA+((DYA2/(DYA2+DYB3))*(XB-XA))
C     WRITE(O,2)XI
      RETURN
      END
      END
      SUBRØUTINE ITER2(XA,XB,YA,YB,ZA,ZB,XI,DYI,DYA1,DYA2,DYB3,DYB4,
     &YI,ZI,N)
      XIA=XI
      IF(YA-ZA)99,99,1D0
99    DYI=ZI-YI
C     WRITE(D,1)DYI
1     FØRMAT(1X,2F15.7)
      IF(DYI)200,20D,300
1DD   DYI=YI-ZI
      IF(DYI)4D0,4DD,500
20D   XI=XB-((DYB4/(DYB4+DYA1))*(XB-XA))
C     WRITE(D,1)XI
      RETURN
3D0   RETURN
40D   XI=XB-((DYB3/(DYB3+DYA2))*(XB-XA))
      RETURN
```

```
500     RETURN
        ENO
        END
        SUBROUTINE ITER3(XA,XB,YA,YB,ZA,ZB,XI,DYI,OYA1,DYA2,DYB3,OYB4,
       &YI,ZI,N)
        IF(YA-ZA)99,99,100
99      DYI=ZI-YI
C       WRITE(0,1)DYI
1       FØRMAT(1X,2F15.7)
        IF(DYI)200,200,300
100     DYI=YI-ZI
C       WRITE(0,1)OYI
        IF(DYI)400,400,500
200     XIA=XI
        DYI= ABS(DYI)
        XI=XIA-((DYI/(DYI+DYA1))*(XIA-XA))
C       WRITE(0,1)XIA,XI
C       WRITE(0,1)DYI,OYA1
        RETURN
300     XIA=XI
        DYI= ABS(DYI)
        XI=XIA+((DYI/(OYI+OYB4))*(XB-XIA))
        RETURN
400     XIA=XI
        DYI= ABS(DYI)
        XI=XIA-((DYI/(DYI+DYA2))*(XIA-XA))
        RETURN
500     XIA=XI
        DYI= ABS(OYI)
        XI=XIA+((DYI/(DYI+DYB3))*(XB-XIA))
        RETURN
        END
        END

EØF READ($MAIN$)100
+
```

```
      SUBROUTINE OUTPUT(J)
C     VERSION 20JULY 1970
      DIMENSION S(8),AN(8),AXI(8),AH1(8),AF1(8)
      DIMENSION XPR(8),YPR(8),ANP(8),DP1(8),ANPR1(8)
      DIMENSION ANPR(8),ANNU1(8),H12(8),ANRE2(8)
      DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
      DIMENSION AK23(8),AK34(8),AK45(8),U(8)
      DIMENSIØN AXTHS(8),AXP(8),E1(8),ANS(8)
      DIMENSIØN ØL(8),AE(8),WX(8),HY(8),ALL(8)
      DIMENSIØN CW(8),HW(8),TW(8),ANF(8),AV(8)
      DIMENSIØN CH1(8),CC2(8),S2(8),AN2(8),AH2(8)
      DIMENSIØN K1(8),K21(8),K3(8),K4(8)
      DIMENSIØN ANTU(8),DHT(8),AKWT(8),ANTUI(8),AKP(5),TLX(5)
      DIMENSIØN XPR1(8),YPR1(8),YPR2(8),YPR3(8)
      DIMENSIØN ALAM(8),TX(8)
      CØMMØN S,AN,AXI,AH1,AF1,XPR,YPR,ANP,DP1,ANPR1,ANPR
      CØMMØN ANNU1,H12,ANRE2,DP2,ANPR2,ANNU2,H56, AK23,AK34
      CØMMØN AK45,U,AXTHS,AXP,EI,ANS,ØL,AE,WX,HY,ALL,CW,HW,TW
      CØMMØN ANF,AV,CH1,CC2,S2,AN2,AH2,K1,K21,K3,K4
      CØMMØN T14,P14,VB14,H14,S14,W1
      CØMMØN T15,P15,VB15,H15,S15
      CØMMØN T16,P16,VB16,H16,S16
      CØMMØN DH,TP,SIG,ANRE1,C,FS,RF,ANTU,TS
      CØMMØN ANT1,DH2,SIG1,SIG2,W2,WT1
      CØMMØN DHT,AKWT,ANTUI,MAT,TLX
      CØMMØN BX,BY,ANH,ANC
      CØMMØN XPR1,YPR1,YPR2,YPR3
      CØMMØN ALAM,TX
35    FØRMAT(1X,8HWIDTH X=F15.8,2X,6HINCHES)
36    FØRMAT(1X,9HHEIGHT Y=F15.8,2X,6HINCHES)
37    FØRMAT(1X,9HLENGTH L=F15.8,2X,6HINCHES)
38    FØRMAT(1X,12HCØRE WEIGHT=F15.8,2X,3HLBS)
39    FØRMAT(1X,14HHEADER WEIGHT=F15.8,2X,3HLBS)
40    FØRMAT(1X,13HTØTAL WEIGHT=F15.8,2X,3HLBS)
41    FØRMAT(1X,4H NF=F15.8)
42    FØRMAT(1X,4H AV=F15.8)
43    FØRMAT(1X,3H S=F15.8,3X,4H  N=F15.8,3X, 5H AF1=F15.8)
44    FØRMAT(1X,5H XPR=F15.8,3X,5H YPR=F15.8,3X,5H ANP=F15.8)
45    FØRMAT(1X,5H DP1=F15.8)
46    FØRMAT(1X,5H CH1=F15.8,3X,6H NPR1=F15.8,6H NNU1=F15.8)
47    FØRMAT(1X,5H H12=F15.8)
48    FØRMAT(1X,6H NRE2=F15.8,3X,5H DP2=F15.8)
49    FØRMAT(1X,5H CC2=F15.8,3X,6H NPR2=F15.8,3X,6H NNU2=F15.8)
50    FØRMAT(1X,5H H56=F15.8,3X,5H K23=F15.8,3X,5H K34=F15.8)
51    FØRMAT(1X,5H K45=F15.8,3X,3H U=F15.8,3X,7H AXTHS=F15.8)
52    FØRMAT(1X,5H AXP=F15.8,3X,4H EI=F15.8,3X,4H NS=F15.8)
53    FØRMAT(1X,4H ØL=F15.8,3X,3H E=F15.8)
54    FØRMAT(1X,7I10)
55    FØRMAT(1X,5H NTU=F15.8,3X,6H NTU1=F15.8)
56    FØRMAT(1X,5H AXI=F15.8,3X,5H AH1=F15.8,3X,5H AH2=F15.8)
```

```
57     FØRMAT(1X,4H  S2=F15.8,3X,5H AN2=F15.8)
58     FØRMAT(1X,5H  DHT=F15.8,3X,5H KWT=F15.8)
59     FØRMAT(1X,6H  ALAM=F15.8,3X,4H  TX=F15.8)
60     FØRMAT(1X,6H  YPR1=F15.8,3X,6H  YPR2=F15.8)
61     FØRMAT(1X,6H  YPR3=F15.8)
      WRITE(I2,35)WX(J)
      WRITE(I2,36)HY(J)
      WRITE(I2,37)ALL(J)
      WRITE(I2,38)CW(J)
      WRITE(I2,39)HW(J)
      WRITE(I2,40)TW(J)
       WRITE(I2,55)ANTU(J),ANTUI(J)
      WRITE(I2,41)ANF(J)
      WRITE(I2,42)AV(J)
      WRITE(I2,43)S(J),AN(J),AF1(J)
      WRITE(I2,44)XPR(J),YPR(J),ANP(J)
      WRITE(I2,45)DP1(J)
      WRITE(I2,46)CH1(J),ANPR1(J),ANNU1(J)
      WRITE(I2,47)H12(J)
      WRITE(I2    ,48)ANRE2(J),DP2(J)
      WRITE(I2,49)CC2(J),ANPR2(J),ANNU2(J)
      WRITE(I2,50)H56(J),AK23(J),AK34(J)
      WRITE(I2,51)AK45(J),U(J),AXTHS(J)
      WRITE(I2,52)AXP(J),EI(J),ANS(J)
      WRITE(I2,53)QL(J),AE(J)
       WRITE(I2,56)AX1(J),AH1(J),AH2(J)
       WRITE(I2,57)S2(J),AN2(J)
       WRITE(I2,58)DHT(J),AKWT(J)
       WRITE(I2,59)ALAM(J),TX(J)
       WRITE(I2,60)YPR1(J),YPR2(J)
       WRITE(I2,61)YPR3(J)
       WRITE(I2,54)K1(J),K21(J),K3(J),K4(J)
       RETURN
       END
```

```
        SUBROUTINE CPSUB(XT,YP,ZCP)
        DIMENSION IP(24),IT(14),CP(24,14)
        OPEN(5,INPUT,/CPDAT/)
1       FORMAT(8I7)
        N=1
        NA=8
        I3=5
        I2=1
        DO 10 KIP=1,3
        READ(I3,1)(IP(MIP),MIP=N,NA)
        N=NA+1
        NA=NA+8
10      CONTINUE
2       FORMAT(7I7)
        N=1
        NA=7
        DO11 KIP=1,2
        READ(I3,2)(IT(MIP),MIP=N,NA)
        N=NA+1
        NA=NA+7
11      CONTINUE
3       FORMAT(11F6.3)
        DO12 KCP=1,23
12      READ(I3,3)(CP(KCP,KCT),KCT=3,13)
        CP(1,1)=1.906
        DO13 KCP=6,23
13      READ(I3,3)CP(KCP,2)
        IXT=IFIX(1000.*XT)
        IYP=IFIX(1000.*YP)
        IF(XT-9.468)100,101,102
101     DO103 K=1,23
        IF(IP(K)-IYP)200,201,201
200     IF(K-23)103,202,202
103     CONTINUE
201     KB=K
        KA=K-1
        IF(KA)210,211,212
211     ZCP=CP(1,3)
        GO TO 900
212     DPB=FLOAT(IP(KB)-IP(KA))
        DPP=FLOAT(IYP-IP(KA))
        DCP=CP(KB,3)-CP(KA,3)
        ZCP=(DCP*(DPP/DPB))+CP(KA,3)
        GO TO 900
102     DO300 LT=3,13
        IF(IT(LT)-IXT)301,302,302
301     IF(LT-13)300,303,303
300     CONTINUE
302     LTB=LT
        LTA=LT-1
```

```
      DTB=FLØAT(IT(LTB)-IT(LTA))
      DTT=FLØAT(IXT-IT(LTA))
400   DØ401 LP=1,23
      IF(IP(LP)-IYP)402,403,403
402   IF(LP-23)401,404,404
401   CØNTINUE
403   LPB=LP
      LPA=LP-1
      IF(LPA)410,411,412
411   DCPTB=CP(LPB,LTB)-CP(LPB,LTA)
      ZCP=(DCPTB*(DTT/DTB))+CP(LPB,LTA)
      GØ TØ 900
412   DPB=FLØAT(IP(LPB)-IP(LPA))
      DPP=FLØAT(IYP-IP(LPA))
      DCPTA=CP(LPA,LTB)-CP(LPA,LTA)
      DCPTB=CP(LPB,LTB)-CP(LPB,LTA)
      ZCPTA=(DCPTA*(DTT/DTB))+CP(LPA,LTA)
      ZCPTB=(DCPTB*(DTT/DTB))+CP(LPB,LTA)
      DCP=ZCPTB-ZCPTA
      ZCP=(DCP*(DPP/DPB))+ZCPTA
      GØ TØ 900
1CO   IF(YP-40.)500,501,501
501   DØ503 LP=6,23
      IF(IP(LP)-IYP)504,505,505
504   IF(LP-23)503,506,506
503   CØNTINUE
505   LPB=LP
      LPA=LP-1
      IF(LP -6)510,511,517
511   DTB=FLØAT(IT(3)-IT(2))
      DTT=FLØAT(IXT-IT(2))
      IF(DTT)515,516,517
516   ZCP=CP(6,2)
      GØ TØ 900
517   DPB=FLØAT(IP(LPB)-IP(LPA))
      DPP=FLØAT(IYP-IP(LPA))
      DCPTA=CP(LPA,3)-CP(LPA,2)
      DCPTB=CP(LPB,3)-CP(LPA,2)
      DTB=FLØAT(IT(3)-IT(2))
      DTT=FLØAT(IXT-IT(2))
      ZCPTA=(DCPTA*(DTT/DTB))+CP(LPA,2)
      ZCPTB=(DCPTB*(DTT/DTB))+CP(LPB,2)
      DCP=ZCPTB-ZCPTA
      ZCP=(DCP*(DPP/DPB))+ZCPTA
      GØ TØ 900
500   YP1=((30./1.106)*XT)-177.
      IYP1=IFIX(YP1)
      DCP1=0.618-1.906
      CP1=(((YP1-10.)/30.)*DCP1)+1.906
      DØ 700 LP=1,6
```

```
      IF(IP(LP)-IYP)701,702,702
701   IF(LP-6)700,704,704
700   CONTINUE
702   LPB=LP
      LPA=LP-1
      IF(LPA)710,711,712
711   DTT=XT-6.894
      DTB=9.468-6.894
      DCP=1.781-1.906
      ZCP=DCP*(DTT/DTB)+1.906
      GO TO 900
712   XTB=(YP+177.)*(1.106/30.)
      DTT=XT-XTB
      DTB=9.468-XTB
      DPP=FLOAT(IYP-IP(LPA))
      DPB=FLOAT(IP(LPB)-IP(LPA))
      YP1=YP
      CP1=(((YP1-10.)/30.)*DCP1)+1.906
      DCP=CP(LPB,3)-CP(LPA,3)
      ZCPA=DCP*(DPP/DPB)+CP(LPA,3)
      DZCP=ZCPA-CP1
      ZCP=DZCP*(DTT/DTB)+CP1
      GO TO 900
C     ERROR CODES
202   WRITE(I2,1001)
      GO TO 9999
210   WRITE(I2,1101)
      GO TO 9999
303   WRITE(I2,1201)
      GO TO 9999
404   WRITE(I2,1301)
      GO TO 9999
410   WRITE(I2,14)
      GO TO 9999
506   WRITE(I2,15)
      GO TO 9999
510   WRITE(I2,16)
      GO TO 9999
515   WRITE(I2,17)
      GO TO 9999
704   WRITE(I2,18)
      GO TO 9999
710   WRITE(I2,19)
      GO TO 9999
1001  FORMAT(1X,7HK GT 23)
1101  FORMAT(1X,6HK LT 1)
1201  FORMAT(1X,8HLT GT 13)
1301  FORMAT(1X,8HLP GT 23)
14    FORMAT(1X,7HLP LT 1)
15    FORMAT(1X,8HLP GT 23)
```

```
16      FØRMAT(1X,7HLP LT 6)
17      FØRMAT(1X,8HDTT LT 0)
18      FØRMAT(1X,7HLP GT 6)
19      FØRMAT(1X,7HLP LT 1)
900     CONTINUE
        CLØSE(5)
        RETURN
9999    STØP
        END
```

10000	14700	20000	30000	33213	40000	50000	60000
70000	80000	90000	100000	120000	140000	160000	180000
200000	220000	240000	260000	280000	300000		
6894	8000	9468	10000	12000	14000	16000	
18000	20000	30000	40000	5400001000000			

1.761	1.761	1.693	1.639	1.596	1.561	1.533	1.441	1.394	1.252	1.240
1.715	1.704	1.657	1.613	1.580	1.547	1.523	1.435	1.390	1.252	1.240
1.627	1.636	1.615	1.585	1.557	1.531	1.507	1.434	1.389	1.252	1.240
1.253	1.488	1.530	1.530	1.530	1.502	1.485	1.425	1.386	1.252	1.240
.953	1.415	1.506	1.510	1.505	1.493	1.480	1.420	1.384	1.253	1.240
1.093	1.228	1.440	1.473	1.479	1.473	1.463	1.416	1.382	1.253	1.240
.777	.819	1.340	1.413	1.438	1.443	1.441	1.403	1.377	1.253	1.240
.749	.779	1.228	1.354	1.397	1.415	1.419	1.400	1.374	1.253	1.240
.740	.763	1.111	1.294	1.358	1.385	1.397	1.393	1.372	1.253	1.240
.742	.761	1.007	1.233	1.318	1.357	1.377	1.384	1.365	1.253	1.240
.747	.762	.945	1.175	1.283	1.331	1.356	1.378	1.363	1.253	1.240
.754	.766	.910	1.123	1.244	1.304	1.336	1.367	1.360	1.253	1.240
.788	.781	.879	1.040	1.178	1.254	1.298	1.353	1.353	1.254	1.240
.795	.799	.871	.990	1.123	1.211	1.264	1.344	1.347	1.254	1.240
.819	.821	.872	.964	1.082	1.173	1.234	1.333	1.340	1.255	1.240
.847	.845	.880	.952	1.053	1.143	1.207	1.320	1.337	1.255	1.240
.877	.870	.892	.947	1.035	1.118	1.184	1.311	1.333	1.256	1.240
.904	.896	.907	.949	1.023	1.102	1.166	1.302	1.327	1.256	1.240
.941	.922	.923	.953	1.017	1.087	1.151	1.293	1.324	1.256	1.240
.962	.949	.941	.963	1.017	1.081	1.139	1.286	1.319	1.257	1.240
.993	.977	.960	.973	1.019	1.074	1.131	1.278	1.315	1.257	1.240
1.023	1.005	.979	.985	1.023	1.073	1.125	1.273	1.313	1.257	1.240

0.000

.618
.631
.643
.658
.674
.692
.707
.743
.781
.817
.854
.893
.931
.968
1.007
1.043
1.082

0.00

OPENING FILE 3, SYMBOLIC IN[illegible] / [illegible]

9.43	50.	7.00	1.047	
7.59	14.7	7.00	1.191	
7.59	14.7	13.2	2.017	
6.2	6.54			
1				
0.0080	0.0063	.0050	.5	2000.
10.	5.	3.	2.	1.
2.	1.	.250	.250	.125
.001				
2.	50.			
2				
.008	.0063	.005	.50	2000.
5.	3.	2.	2.	
2.	2.	.250	.250	.125
.001	.002	.90		
2.	30.			
3				
.008	.0063	.005	.5	2000.
10.	5.	3.	2.	2.
2.	1.	.250	.250	.125
.002				
2.	50.			
4				
.008	.0063	.0050	.50	2000.
5.	3.	2.	2.	
2.	1.5	.250	.250	.125
.002	.001	.003	.9	
2.	30.			
5				
.008	.0063	.005	.5	2000.
10.	5.	3.	2.	2.
2.	1.	.250	.250	.125
.003				
2.	150.			
6				
.008	.0063	.0 5	.5	2000.
5.	3.	2.	2.	
2.	1.333	.250	.250	.125
.003	.001	.004	.9	
2.	30.			
7				
.008	.0063	.005	.5	2000.
10.	5.	3.	2.	2.
2.	1.	.250	.25	.125
.004				
2.	200.			

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13. ABSTRACT

The present work comprises a generalized computer program for the performance analysis and study of turbomachine-driven cryogenic systems in general, employing helium as the working fluid.

With the facility of the broad input spectrum incorporated, the effect of numerical changes in all major variables or input parameters may be studied, either individually or in combination as desired.

Systems may also be optimized for minimum size, weight, number of components, and power input requirements.....by judicious selection of the various input parameters.

The porous-plate type heat exchanger is specifically considered (see ref. 5).

Upon activating either one of two input codes, the computer will evaluate heat exchanger characteristics based on use of either AL-1100-F or AL-3003-F as the plate material.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Analytical program. Cryogenic systems. Turbomachine-driven helium cryogenic systems. Heat exchangers, porous plate type in helium cryogenic systems. Performance analysis of turbomachine-driven cryogenic systems, with helium working fluid and porous plate type heat exchangers.						